

Carbon Management for Sustainable Development:

**An examination of potential transition paths for the Saudi Arabian
'national system of innovation' towards a cleaner energy economy**

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ ﴿١﴾

In the name of Allah, the Entirely Merciful, the Especially Merciful (Quran 1:1).

ظَهَرَ الْفَسَادُ فِي الْبَرِّ وَالْبَحْرِ بِمَا كَسَبَتْ أَيْدِي النَّاسِ لِيُذِيقَهُمْ
بَعْضَ الَّذِي عَمِلُوا لَعَلَّهُمْ يَرْجِعُونَ ﴿٤١﴾

Corruption has appeared throughout the land and sea by [reason of] what the hands of people have earned so He may let them taste part of [the consequence of] what they have done that perhaps they will return [to righteousness] (Quran 30:41).

إِنَّا عَرَضْنَا الْأَمَانَةَ عَلَى السَّمَوَاتِ وَالْأَرْضِ وَالْجِبَالِ فَأَبَيْنَ أَنْ
يَحْمِلْنَهَا وَأَشْفَقْنَ مِنْهَا وَحَمَلَهَا الْإِنْسَانُ إِنَّهُ كَانَ ظَلُومًا جَهُولًا ﴿٧٢﴾

Indeed, we offered the Trust to the heavens and the earth and the mountains, and they declined to bear it and feared it; but man [undertook to] bear it. Indeed, he was unjust and ignorant (Quran 33:72).

قَالَ يَاقَوْمِ أَرَأَيْتُمْ إِن كُنتُ عَلَىٰ بَيِّنَةٍ مِّن رَّبِّي وَرَزَقَنِي مِنْهُ رِزْقًا
حَسَنًا وَمَا أُرِيدُ أَنْ أَمْلِكَ لَكُمْ إِلَىٰ مَا أَنهَضَكُم عَنْهُ إِن أُرِيدُ
إِلَّا الْإِصْلَاحَ مَا اسْتَطَعْتُ وَمَا تَوْفِيقِي إِلَّا بِاللَّهِ عَلَيْهِ تَوَكَّلْتُ وَإِلَيْهِ
أُنِيبُ ﴿٨٨﴾

He said, "O my people, have you considered: if I am upon clear evidence from my Lord and He has provided me with a good provision from Him? And I do not intend to differ from you in that which I have forbidden you; I only intend reform as much as I am able. And my success is not but through Allah. Upon him I have relied, and to Him I return (Quran 11:88).

Dedication and Memoriam

هُوَ الْحَيُّ لَا إِلَهَ إِلَّا هُوَ فَادْعُوهُ مُخْلِصِينَ لَهُ الدِّينَ الْحَمْدُ
لِلَّهِ رَبِّ الْعَالَمِينَ

He is the Ever-Living; there is no deity except Him, so call upon Him, [being] sincere to Him in religion. [All] praise is [due] to Allah, Lord of the worlds (Quran 40:65).

I dedicate this work to the loving memory of my father, Dr. Youssef M. S. Mansouri (1938-2009), who saw, inspired and supported the start of this work but has passed away before it was complete. *May Allah's mercy be upon him and may my work reach him.*

I dedicate this work to my mother Zohour Mukhtar and my husband Ammar Youssef.

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Abstract

Since the first industrial revolution, rising carbon emissions have caused harmful effects on our environment. There is a broad consensus that climate change is happening and that it is as a result of anthropogenic carbon emissions, primarily from burning fossil fuels. This raises concern for the future of our carbon-based world energy and world economy, particularly with economies heavily dependent on oil, such as Saudi Arabia. This dissertation aims to answer the question: How could Saudi Arabia, given its oil-based economy and vast oil reserves, respond to the challenges of climate change and the world's transitioning towards environmental sustainability, and away from fossil fuels.

Two studies have been conducted, a quantitative study and a qualitative study. The first study examined the Saudi energy sector, 40 life cycle assessment (LCA) studies on both carbon capture and storage (CCS) and solar photovoltaic (Solar PV) were used to create 12 scenarios for 3 growth cases from year 2010 to 2025. Results showed massive reductions in carbon dioxide emissions in all scenarios.

The second study examined the economy of Saudi Arabia, using 30 interviews with participants from across the economy, to materialise the Saudi national system of innovation. Major forces of the economy and their relationships have been identified and discussed.

Using both studies, transition paths of the Saudi NSI towards a sustainable and cleaner energy economy were then constructed and discussed. A Saudi sustainable carbon management 'system of innovation' (SSCMSI) was proposed. Given Saudi Arabia's heavy dependence on oil, which characterised its NSI fabric, constructing an NSI around its energy sector was important. The proposed SSCMSI role includes: accelerating innovation in the energy sector, encouraging energy efficiency, accelerating the use of renewable energy, improving market conditions, supporting technology transfer from advanced economies, utilising international cooperation and mobilizing private sector investment in energy.

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List of Acronyms and Abbreviations

A	Aquifer
a-Si	Amorphous
BESOM	Brookhaven Energy System Optimization Model
C	Coal
CCS	Carbon capture and storage
CdTe	Cadmium telluride
CH ₄	Methane
CIS	Copper indium gallium (di)selenide
CM	Carbon management
CO ₂	Carbon dioxide
COA	Central Operating Area
Con III-V multi-jun	FLATCON using III–V semiconductor multi-junction solar cells
CR	Crude oil
DOE	Department of Energy
ECRA	Electricity and Cogeneration Regulatory Authority
ENPEP	Energy and Power Evaluation Programme
EOA	Eastern Operating Area
EOR	Enhanced oil recovery
EPBT	Energy pay back time
Eq.	Equivalent
ER	Enhanced recovery storage
ETA	Energy technology assessment
ETSAP	Energy Technology Systems Analysis Programme
F	Full LCA
FG	Foreground LCA
G	Geological storage
GDP	Gross Domestic Product
GEM	Global energy modelling
GHG	Greenhouse gases
GJ	Giga joules
gm	Grams
GWh	Giga watt hour
GWP	Global warming potential
H	Hybrid LCA

H ₂ O	Water
HCl	Hydrochloric acid
HYSYS	Process modelling software
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IGCC	integrated gasification combined cycle
IOA	Isolated Operating Area
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producers
ISO	International Standards Organisation
KFUPM	King Fahd University for Petroleum and Minerals
kg	Kilograms
km	Kilometre
KSA	Kingdom of Saudi Arabia
kWh	Kilowatt hour
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LEAP	Long-range Energy Alternatives Planning
MAREL	Multi-Area Reliability Analysis Program
MARKAL	Market Allocation Model
mc-Si	Multi/poly crystalline
MEB	Mass energy balance LCA method
MEP	Ministry of Economy and Planning
MJ	Mega joules
MLP	Multilevel Perspective
MW	Megawatt
N/A	Not available/applicable
N ₂ O	Nitrous oxide
NEEDS	New Energy Externalities Development for Sustainability
NG	Natural gas
NGCC	Natural gas combined cycle
NH ₃	Ammonia
NO _x	Nitrogen oxide
NSI	National System of Innovation

O	Ocean storage
OPEC	Organization of the Petroleum Exporting Countries
Ot	Other
Oxy	Oxyfuel capture
P	Pipeline transport
PME	Presidency of meteorology and environment
PoC	Post combustion capture
PrC	Pre combustion capture
QD	hybrid quantum dot (QD)-based solar cells
RE	Renewable energy
RET	Renewable energy technologies
RETScreen	Renewable Energy and Energy-efficient Technologies Screening system
S	Shipping transport
sc-Si	Single/mono-crystalline
SCR	Selective Catalytic Reduction
SEC	Saudi Electricity Company
Seq	Sequestration
SI	System of Innovation
SOA	Southern Operating Area
SOx	Sulfur oxide
SSCMSI	Saudi Sustainable Carbon Management System of Innovation
SSI	Sectoral System of Innovation
SWCC	Saline Water Conversion Corporation
t	Tonnes
TIMES	Integrated MARKAL EFOM system
TSI	Technological System of Innovation
UNFCCC	United Nations Framework Convention for Climate Change
US	United States
VOCs	Volatile organic compounds
WOA	Western Operating Area

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1 Setting the Scene

This chapter introduces the core research problem and sets the scene for the rest of the dissertation. It starts by providing a background to the research and then defines a problem statement, sets the research questions that this dissertation aims to answer and specifies the research objectives. It then explains the nature of the research and methodology followed throughout the dissertation, outlines a structure for the dissertation, and finally states the dissertation's expected contributions.

Chapter Content:

- 1 Setting the Scene
 - 1.1 Background
 - 1.2 Problem Statement
 - 1.3 Research Questions and Objectives
 - 1.4 Methodology
 - 1.5 Structure of the Thesis
 - 1.6 Expected Contributions

1.1 Background

After the industrial revolution between the 18th and 19th century, hydrocarbons have emerged as an essential source of energy to the world, and have thus provided the foundations of our modern civilisation. Industrialisation, which started in Great Britain and was subsequently spread into Europe, North America and eventually the world, has only recently been correlated with climate change through the emissions of carbon dioxide (CO₂), the by-product of burning fossil fuels. Today, the world economy is based on carbon, as it remains heavily reliant on fossil fuels, which currently accounts for nearly 86% of the world's energy mix (BP 2009). It is likely that fossil fuels will continue to be the major source of energy, at least in the coming decades, especially with the dramatic rises in energy demands in fast industrialising economies, such as China and India.

Today, the scientific consensus reiterates that climate change is occurring and it is as a result of anthropogenic (human-induced) carbon emissions. It has also warned “warming of the climate system is unequivocal” (IPCC, 2007). Observed changes shall be presented later in chapter 2. Climate change has been, and continues to be, a hot topic gaining increasing importance but also spurring a lot of controversial debates.

There are some critics that challenge the scientific basis of global warming, for example some argue that global warming is not attributed to anthropogenic emissions nor will it impact harmful effects but rather believe that it is merely a natural phenomena that could be attributed to *natural variability* primarily induced by solar variations, and in some parts of the world, climate change may impact positively (see chapter 2). Whether or not climate change is attributed to anthropogenic emissions caused by the burning of fossil fuels is not in the scope of this research. It is, however, important to acknowledge that such a consensus is strongly embraced by the international community and therefore, exerts environmental pressures on countries, which makes a transition away from fossil fuels and towards a more diversified portfolio of energy sources and technologies *inevitable*. Therefore, ‘sustainable

development' is increasingly becoming the desired path which international organisations and countries alike aspire to pursue so as to achieve the right balance between its respective economy, society and the environment.

As a result, interest in research and development into cleaner energy technologies is increasing, such technologies include carbon capture and storage (CCS), renewable energy, nuclear energy and energy efficiency. Hence, the climate change debate fuels the changing dynamics of world energy towards a more diversified and sustainable form of energy. This paradigm shift is also motivated by other challenges that face the oil industry. These include the fluctuation of oil prices, the theory of peak oil, political unrest and instability of oil-rich Middle East, and the security concerns of oil-importing nations that are dependent on 'foreign' Middle East oil. Altogether, further motivates such a transition away from fossil fuels. Leading oil-importing nations, such as United States, United Kingdom, and Nordic countries have energy policies that aim to contribute in their shift away from fossil fuels and towards a more diversified, cleaner and sustainable energy mix.

Therefore, oil exporting countries and especially those whose economies are heavily dependent on oil will suffer if dynamics in the global energy market affect oil demand. Saudi Arabia for example is heavily dependent on oil exports, as shall be presented in chapter 3. Saudi-oil importing countries are likely to follow on the same shift away from fossil fuels, presenting more intensified challenges to oil-based Saudi Arabia.

Saudi Arabia is a world's energy provider and enjoys a powerful role in the Organisation of Petroleum Exporting Countries (OPEC), being one of its founding members and also its major swing producer¹, it also enjoys a

¹ Saudi Arabia uses its petroleum reserves to maintain supplies of oil and stabilize oil prices, it is the perhaps the only OPEC member with such power (see for example: Mabro, 1975; Erickson, 1980; Alhajji and Heuttner, 2000)

leadership role in oil-rich Middle East and its current instability² breeds much concern and interest from the West. Not only due to its massive oil reserves but also for embracing Islam's two Holy mosques of Medina and Makkah, the capital of the Muslim world. Moreover, Saudi oil fuels the world's two largest economies of USA and Japan and the two fastest developing economies of China and India. These countries' efforts to diversify their energy mix portfolio are taking place and vary greatly. For example, Japan may be the first of the four to reduce its dependence on oil due to national security reasons of an economy with a highly industrial base and very limited natural resources, while America's economy is around 90% *locked-in* fossil fuels. China on the other hand is expected to be the largest consumer of Saudi oil, strengthening a progressively strategic Sino-Saudi bilateral relation. Saudi oil will likely continue to play an essential role in world oil markets in the decades to come.

1.2 Problem Domain

Faced by the challenge of climate change, the question of sustainability becomes pertinent to Saudi Arabia, this is its balancing between the economy, society and the environment. This translates into a number of challenges for Saudi Arabia:

(1) Climate change is forecasted to impact the world: impacting its ecology, fresh water and food systems; climate change will also impact Saudi Arabia and the surrounding regions, raising concerns for ecological catastrophe and negative subsequent events.

- a. Climate impacts to the world would likely impact Saudi Arabia's oil exports, when countries take action and move away from fossil fuels.

² Middle East instability could be defined by a chain of ongoing events: the current seven-years-old occupation of Iraq by US and UK forces; the five decade old Israel/Palestinian conflict; and the Iran nuclear threat to international security; terrorism; and most recently, the Arab Spring started by the revolutions in Tunisia and Egypt which overthrew current regimes, and the continued 'dominoes effect' with current revolutions in Syria, Libya and Yemen (and briefly in Bahrain) amid bloody crack-downs.

- b. Climate impacts on Saudi Arabia will directly pressurize the country to take a transition path towards sustainability.
- (2)** Climate change gaining momentum and fuelling interests and research in alternative energy, which makes a world shifting away from fossil fuel possible, perhaps in the near future. Reducing dependence on oil will reduce Saudi oil exports, which in turn will reduce its government revenues and challenge its economic base.
- (3)** Climate change is embraced by the international community as a priority, and a number of international initiatives have taken place and continue to take place, environmental treaties are possible, these, especially if enforced, will oblige countries (including Saudi Arabia) to reduce their CO₂ emissions.
- (4)** Other challenges facing Saudi's oil industry include:
 - a. Other countries' national security issues which encourage their transition to lessen their dependence on oil countries such as Saudi Arabia
 - b. Oil price fluctuations and especially high oil prices will encourage a further transition of world economies away from fossil fuels and towards alternative energy sources
 - c. High energy consumption in Saudi Arabia forms another challenge for Saudi's oil sector, it is expected to reduce oil exports and therefore reduce revenues to be generated from oil exports

The desired states for Saudi Arabia according to the stated problems are as follows, firstly, it must limit the impacts of climate change so as to prevent ecological damages to the environment. Secondly, it must pursue alternative energy technology and exploit its renewable energy sources to remain as the leader in the energy market. Thirdly, it must diversify its energy portfolio and economy so as to survive even when oil demand is disrupted or in worse case halted.

1.2.1 Problem Statement

Saudi Arabia is facing a number of challenges that invites a restructuring to (1) its economy, (2) the oil industry, and (3) the shape of the global energy market. Hence, its role, its economy and its future position in the global energy market will be *reshuffled*. It is vital for Saudi Arabia to research ways into how it could pursue sustainability while allowing its economic development to progress and flourish.

These are all challenges that have erupted over the last decades that could shape the fate of Saudi Arabia. How will Saudi Arabia respond to these challenges that urge it to pursue a transition towards sustainability, which also means curbing carbon emissions, the by-product of oil—Saudi Arabia's *bloodline*.

1.3 Research Questions and Objectives:

1.3.1 Research Questions

This dissertation aims to answer the central research question: How could Saudi Arabia, given its oil-based economy and vast oil reserves, respond to the challenges of climate change and the world's transitioning towards environmental sustainability, and away from fossil fuels?

The question is further broken down into five sub-questions:

1. Why is a transition to sustainability in Saudi Arabia important?
2. What is Saudi Arabia's NSI?
3. What is the portfolio of carbon management technologies that could assist Saudi Arabia in such a transition?
4. What might be the socio-technical transition paths that Saudi Arabia could pursue for sustainability?
5. What are the energy and innovation policies that Saudi Arabia could adopt to achieve sustainability?

1.3.2 Research Objectives:

- (a) Explain what climate change is and how its global and regional impact affects Saudi Arabia
- (b) To *materialise* the characteristics of a 'national system of innovation (NSI),
- (c) Identify a portfolio of carbon management technologies for KSA
- (d) Construct transition paths for the energy sector towards sustainability
- (e) Recommend technology innovation policy to *spur* energy technology innovation within an economy.

The first objective is to review the relevant literature that will present the problem issues at hand, these are the subjects of climate change, the Saudi Arabian economy, energy sector and role in the global oil market, presenting three-fold challenges to the Kingdom of Saudi Arabia: (1) the direct projected climate change affecting Saudi Arabia's ecology, economy and society and therefore the pressure to address such challenges by pursuing sustainability; (2) the climate change projections affecting the world, and therefore, driving the world towards a more diversified and 'sustainable' energy resources shifting away from fossil fuels. As a consequence, Saudi Arabia must deal with a changing world dynamics in the energy market and a possible reduction of the role of Saudi oil. And (3) Saudi Arabia to pursue sustainability and balance between its economy, environment and society, therefore it must also deal with its own challenges of an oil-dependent economy and energy portfolio.

The second objective is to identify the country's 'innovative capacity' by conducting qualitative in-depth interviews with 30 practitioners in the field, examining the Kingdom's national system of innovation (NSI) and identifying its position and readiness for a transition towards (1) a cleaner energy economy, without jeopardizing its position in the energy market, and (2) a more diversified economy.

The third objective is to put together a portfolio of carbon management technologies selected to satisfy the country's competitive advantage to assist in a transition towards sustainability.

The fourth objective is to illustrate a transition path to a cleaner energy generation/production by taking the power sector as a case study and applying CCS and Solar PV technologies to the Saudi power sector.

The fifth and last objective is to present policy recommendations for such a transition in the Kingdom.

1.4 Methodology

The purpose of this study is to examine transition paths of the national system of innovation (NSI) for the Kingdom of Saudi Arabia (KSA). The transition path will be generally defined as a path that allows Saudi Arabia to tackle the climate change problem via spurring innovation in carbon management (CM) technologies and pursuing sustainable development of its oil-based economy. In doing that, the NSI framework is applied to *materialize* Saudi's NSI, the socio-technical transition theory is also used to define transition paths and the framework of sustainability is used to set a direction of such transition paths, with an emphasis on the *environmental* dimension for the energy sector for a transition towards a cleaner energy economy.

The nature of the research is a case study examining KSA, a primarily qualitative inquiry which also uses quantitative analysis for the power sector sub-case study. Research methods include primary data of in-depth interviews and forecast of Saudi Arabian electricity demands and carbon dioxide emissions. Secondary data, such as books, academic journals, government reports and academic research have been used for the study.

1.5 Structure of the Thesis

1	<i>Introduction</i>	Setting the Scene
2	<i>Background 1</i>	Climate Change
3	<i>Background 2</i>	Saudi Arabia
4	<i>Theories & Methodology</i>	Conceptual and Theoretical Frameworks & Methodology
5	<i>Technology</i>	A Portfolio of Carbon Management Technologies

6	<i>Findings 1 [quan]</i>	The Transition of the Saudi Electricity Sector Towards Cleaner Energy - Reporting LCA Studies Results
7	<i>Findings 2 [qual]</i>	The Saudi NSI - Reporting interview results
8	<i>Findings, analysis & discussion</i>	Saudi NSI in transition pathways to sustainability
9	<i>Conclusion</i>	Concluding chapter

Chapter 1 presents an introduction to the dissertation, it explains the nature of the research, its research questions and objectives as well as the expected contributions from this research, and it also lays the structure of the dissertation.

Chapter 2 and 3 provides a background to the problem, chapter 2 is on the subject of climate change as a prime motivator for the topic, it also explains sustainable development and what that means to the country case of Saudi Arabia. A summary on the issues related to climate change is provided, including: its origins, brief understanding of the science, key indicators, future implications and critics of climate change. Next, an overview on some international environmental treaties is presented and the impact on the country case of Saudi Arabia is explained.

Next in chapter 3, the Saudi Arabian economy and energy sector is overviewed, starting with an introduction into the case study, its importance, major economic development, energy sector and the national efforts, which pertains to climate change in specific and sustainability in general.

Chapter 4 presents an articulation of the conceptual and theoretical frameworks to be used in this dissertation; namely, the national system of innovation (NSI) framework, transition theories, and reflexive governance for sustainability. The second part provides an explanation on the methodology followed in this dissertation, including a qualitative inquiry into the Saudi economy as a case study for NSI, explaining research methods used such as interviews, and also a quantitative analysis on research methods used such as results from incorporating Life Cycle Assessment (LCA) studies on the energy sector. The chapter also provides a section on methodology.

Chapter 5 is the technology chapter, which puts together a portfolio of carbon management technologies for Saudi Arabia, this chapter presents a technical overview for the different technological options that Saudi Arabia could pursue in light of the background forces presented in chapter 2 and 3. First, a brief explanation of the global carbon cycle with a focus on climate change is presented, then an introduction to different carbon management technologies is provided with summaries of the current efforts and projects, such technologies includes carbon capture and storage (CCS), solar photovoltaic (Solar PV), carbon-based materials and nanomaterials, and mineral carbonation and carbon industrial uses.

Chapter 6 is the first part of findings which uses a quantitative inquiry, it reports the results of incorporating Life Cycle Assessment (LCA) studies onto the energy sector in Saudi Arabia for a transition to cleaner energy, the chapter provides a projection of energy consumption and CO₂ emissions in the electricity sector for Saudi Arabia using the case for carbon capture and storage installation and solar photovoltaic generation. This chapter examines the Saudi Arabian electricity sector and illustrates transition paths to cleaner energy generation by applying both CCS technologies and Solar PV technologies to the electricity generation sector. By first providing a brief overview on the Saudi Arabian electricity sector, followed by a summary of the literature review on LCA Studies conducted for both CCS and Solar PV. The results are presented after applying these cleaner energy technologies and their CO₂ reduction mechanisms in different scenarios, projecting energy consumption and different CO₂ emissions scenarios for Saudi Arabia for the period 2010 to 2025.

Chapter 7 is the second part of findings using a qualitative inquiry; it reports the results of 30 interviews with practitioners in the field. The research investigated the major forces that shape the Saudi economy and define its innovative capacity that is pertinent to sustainability in general and the energy sector in particular. The results will inform the materialising of the Saudi NSI in the next chapter.

Chapter 8 builds on the merging of the findings and providing analysis and discussion on the overall thesis. Using the conceptual and theoretical frameworks (chapter 4) to analyse the case study, this chapter takes the findings (chapter 6 and 7) to a higher level and articulate the Saudi NSI and transition pathways to cleaner energy.

Chapter 9 is the final chapter of the dissertation. It evaluates the extent to which the research questions have been addressed, setting out the main limitations, and describing key points of further work.

1.6 Expected Contributions

1.6.1 Methodological Contributions

The use of mixed methods in this dissertation of both qualitative and quantitative nature for answering the research questions; the conceptual and theoretical frameworks used are from both realms, for example, the quantitative-based concepts and models used are (1) LCA approach from the science and engineering domain and (2) the qualitative-based concepts and theories are from the social sciences domains, these include (1) NSI, (2) transition theories, (3) reflexive governance, together are brought together to answer the questions.

1.6.2 Theoretical Contributions

- (1) Incorporating sustainability as a tool guiding the direction for NSI's transition paths.
- (2) Using LCA studies reviews as a tool for governance towards sustainability
- (3) Using the reflexive governance framework, NSI and transition theories to develop transition pathways towards sustainability

1.6.3 Empirical Contributions

- (1) The *materializing* of Saudi's NSI and transition paths towards sustainability

- (2) An illustrative and technical case of such a transition path for the Saudi energy sector has been analysed using life cycle assessment (LCA) studies conducted in the literature to assess the technology of Carbon Capture and Storage (CCS) and Solar Photovoltaic (Solar PV) and its prospects to reducing life-cycle carbon emissions from power generation. The case study of the power sector in Saudi Arabia to be analysed to show an illustrative example of how will applying CCS and PV to the electricity generation affect the Saudi energy sector and the level of CO₂ emissions in different scenarios.
- (3) Policy recommendations using the Reflexive Governance approach

2 Climate Change

"Warming of the climate system is unequivocal." – IPCC 2007

This chapter provides a background to the problem that primarily motivates the topic. It starts by presenting the scientific consensus on climate change and main arguments that support anthropogenic climate change, presenting the key indicators, causes, and projections with a focus on the impacts of climate change on Saudi Arabia and its stance on climate policy. An antidote discussion on natural climate variability is then provided, following that, a summary of the main international environmental treaties on climate change with a special focus on Saudi Arabia's direct/indirect environmental obligations.

Chapter Content:

2 Climate Change

- 2.1 Historical Origins
- 2.2 The Greenhouse Effect
- 2.3 Key Indicators of Climate Change
- 2.4 Projections of Climate Change and its impacts
- 2.5 Causes of Climate Change
- 2.6 Critics of Climate Change
- 2.7 Direct impacts on Saudi Arabia
- 2.8 Main International Environmental Treaties on Climate Change
- 2.9 Islamic Principles and Saudi Arabia's Stance on Climate Change
- 2.10 Summary of Environmental Challenges for Saudi Arabia

2.1 Historical Origins

The origins of the study of climate change goes back to the 19th century when many scientists, such as Tyndall, Fourier, Langly, Arrhenius and Högbom, conducted studies on the effects of the atmosphere on temperature to understand the phenomena of ice ages (AIP 2009). In the 1860s, John Tyndall, a prominent physicist of his time, studied the infrared absorptive powers of the gasses and was first to recognize Earth's greenhouse effect; he suggested that slightest changes in the atmospheric composition could result in climatic variations (NASAd 2009). In 1896, building on works by Fourier, Tyndall and Langley, Svante Arrhenius published the first paper that quantifies the contribution of carbon dioxide to the greenhouse effect (Upperbrink 1996, Arrhenius 1896) and was the first to speculate that carbon dioxide levels fluctuations could alter the surface temperature through the greenhouse effect (NASAd 2009). It is interesting to note here that these researches were motivated to study such correlation to 'avoid' another ice age, they were in favour of a warmer climate (AIP 2009). For example, Arrhenius (1908) believed that a warmer climate would be a positive change for the world, which he argued is 'needed' to feed a booming population. He suggested that the increased carbon emissions induced by man would be strong enough to 'save the world' and prevent Earth from entering into a new ice age (AIP 2009, Arrhenius 1908).

From the 1950s, interest in studying the climate was sparked again when a few researchers discovered that a global warming was possible. In the 1960s, Keeling measured the carbon emissions in the atmosphere and noted it was rising and realised it has a crucial role in climate change (AIP, 2009). Perhaps it is important to mention that not until the late 1970s did the world approach the study of rising carbon dioxide and its correlation to a 'warming' climate as a negative happening. Today, combating climate change has become a global priority and is part of many international agendas and treaties as we will see in the sections to come.

2.2 The Greenhouse Effect

To understand climate change, it is important to first understand the greenhouse effect. The temperature of Earth is a balance between *solar radiation*, energy coming from the Sun to Earth, and *invisible infrared radiation*, energy leaving Earth to outer Space. Earth's atmosphere is composed of 78% nitrogen, 21% oxygen, and 1% other gases. However, the interest is in the greenhouse gases (GHG) that constitute the blanket which surrounds Earth, this keeps it at an essential 14°C temperature to sustain life on the planet (NASA 2009, IPCC WGI 2001). The most important GHG in Earth's atmosphere are: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), water vapour (H₂O), ozone (O₃), and chlorofluorocarbons (CFC's).

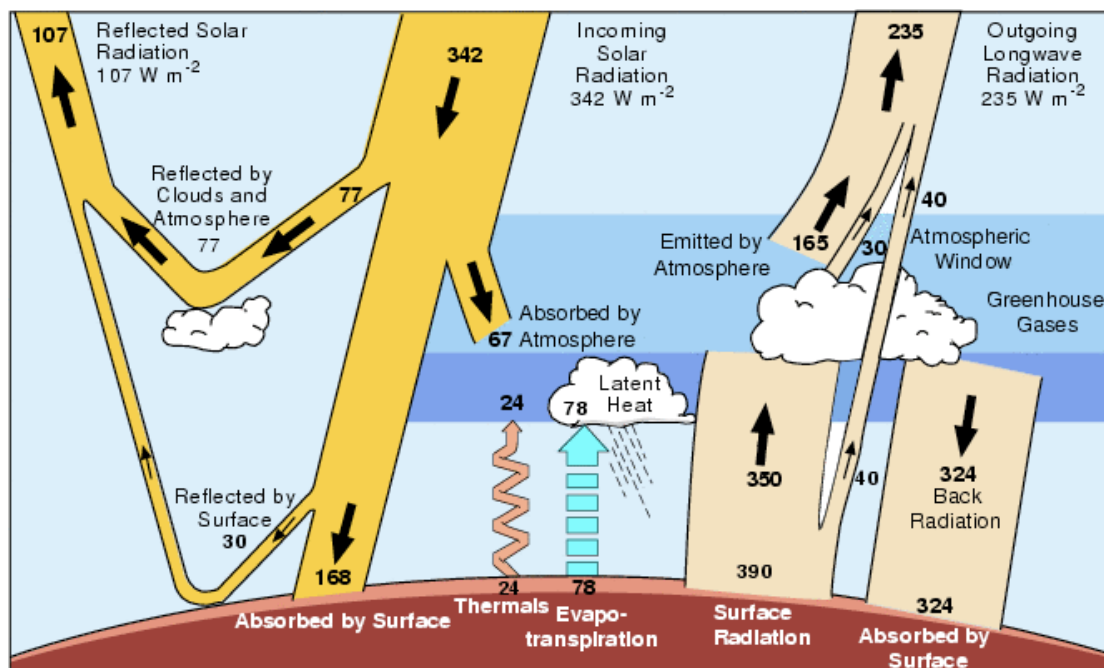


Figure 2-1 Earth's Annual Global Mean Energy Budget, units are in watts per square metre (W m^{-2}) (Source: Kiehl and Trenberth 1997, p. 206)

The figure shows the annual average energy budget of Earth. Of the amount of incoming solar radiation (342 W m^{-2}), some are reflected by clouds (77 W m^{-2}) and atmosphere's GHGs (67 W m^{-2}), the rest is absorbed by Earth's surface (168 W m^{-2}). In turn, Earth's surface and the atmosphere's GHG release the same amount of outgoing long-wave (infrared) radiation (350 W m^{-2}) to balance out the energy budget. Note that the GHG

radiates in all directions, so some of the radiation is directed back to the surface of Earth, keeping it at 14°C (Kiel and Trenberth 1997).

2.2.1 The Global Carbon Cycle

To understand climate change we must first attempt to understand our global carbon cycle, which influences and is influenced by the climate system. According to a study by the Woods Hole Research Centre (WHRC, 2009), the following is a formula that summarises the fluxes taking place within the global carbon cycle:

<p style="text-align: center;"> Atmospheric increase = Emissions from fossil fuels + Net emissions from changes in land use - Oceanic uptake - Missing carbon sink </p>

Carbon is ranked 16 as the most abundant element on Earth (Freemantle, 1987 cited in Chemgapedia, 2009). Carbon is also known as the ‘building blocs of life on Earth’ because of its nature in enabling other elements to attach to it and form long chains. “*Carbon constitutes most organic matters from fossil fuels to complex molecules such as DNA and RNA that are responsible for genetic reproduction*” (Chemgapedia, 2009).

Table 2-1 Main Storage and Fluxes of Carbon (Source: Chemgapedia, 2009)

Stores	Fluxes
CO ₂ in atmosphere	Ocean water photosynthesis and dissolved atmospheric CO ₂
Biomass carbon / organic matter in soils	Vegetation, animals respiration
Fossil and sedimentary deposits	Burial, sedimentation, chemical ppte
Sea bed calcium carbonate deposits in shells of marine organisms	Erosion and mining

According to Chemgapedia (2009) there are a number of natural storages for Carbon as shown on Table 1:

1. Lithosphere (Earth's crust) in organic and inorganic forms
 - a. Inorganic forms:
 - i. Carbon dioxide (CO_2) in the atmosphere
 - ii. CO_2 in dissolved water:
 1. Bicarbonate
 2. Carbonate rocks (limestone, CaCO_3)
 3. Deposits of coal, oil and natural gas – derived from organic matter
 - b. Organic forms:
 - i. Most living matter
 - ii. Litter and humic substances found in soil

Although the above shows an understanding of where carbon dioxide resides in nature, however, these storages and fluxes are not balanced. According to Oak Ridge National Laboratory (ORNL), scientists are yet to balance all of the carbon fluxes in our global carbon cycle from 1800 to present time (ORNL, 1990).

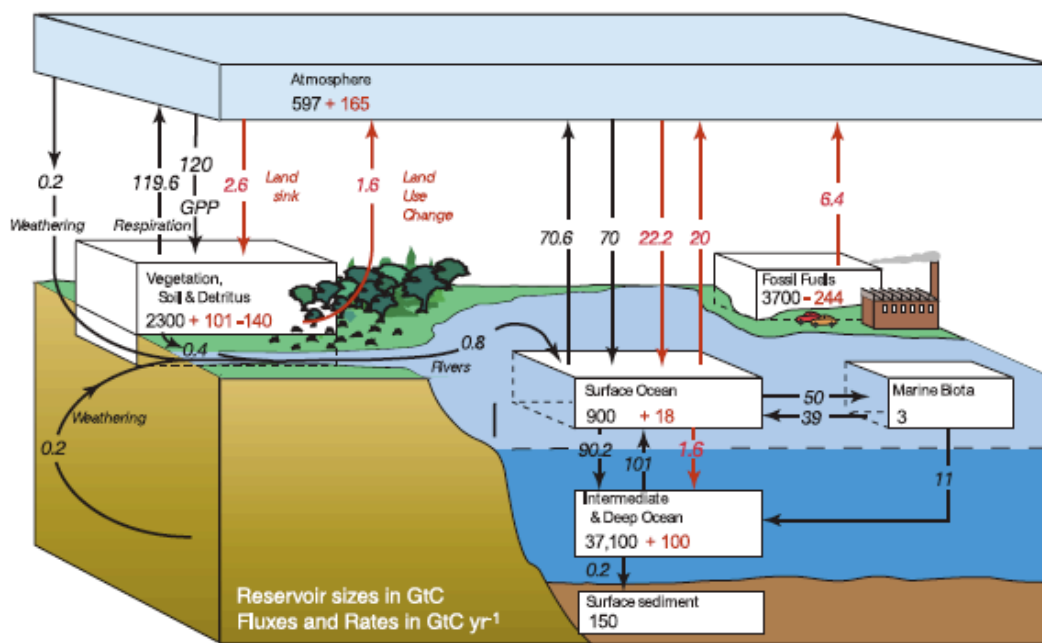


Figure 2-2 The Global Carbon Cycle (Source: Denman *et al.* 2007)

The figure shows a summary of the global carbon cycle in GigaTons of Carbon (GtC) through four cycles for carbon (Denman *et al.* 2007):

- (1) Photosynthesis and Respiration – Plants and trees use sunlight to transform carbon dioxide into nutrients through *photosynthesis* to grow, plants store carbon dioxide as they grow. However, they also produce carbon dioxide and release it to the atmosphere through *respiration*.
- (2) Decomposition – When plants and animals die, they *decompose* into the soil. In their decomposition they constitute carbon dioxide and over the long-run transform into fossil fuels.
- (3) Diffusion – Gasses (including carbon dioxide) *diffuse* between the atmosphere and the ocean's surface. In the ocean, plants use this carbon dioxide for photosynthesis, animals in the ocean eat plants (which contain carbon dioxide). Plants and animals in the ocean produce back carbon dioxide into the ocean for their respiration. When they die, plants and animals decompose in the ocean producing CO₂ which either sinks in deep ocean and dissolves or settle at the ocean floor and get buried in sediment.

(4) Circulation – the water circulated between the deep ocean and the surface also carries carbon, some of that is transported to the surface and to the atmosphere.

2.2.2 Global Warming

Having understood the greenhouse effect and the global carbon cycle, global warming is explained here as an effect of an 'enhanced' greenhouse effect, caused by an imbalance in the carbon cycle which causes a 'thickened' blanket of GHG surrounding earth, which traps more heat at the surface.

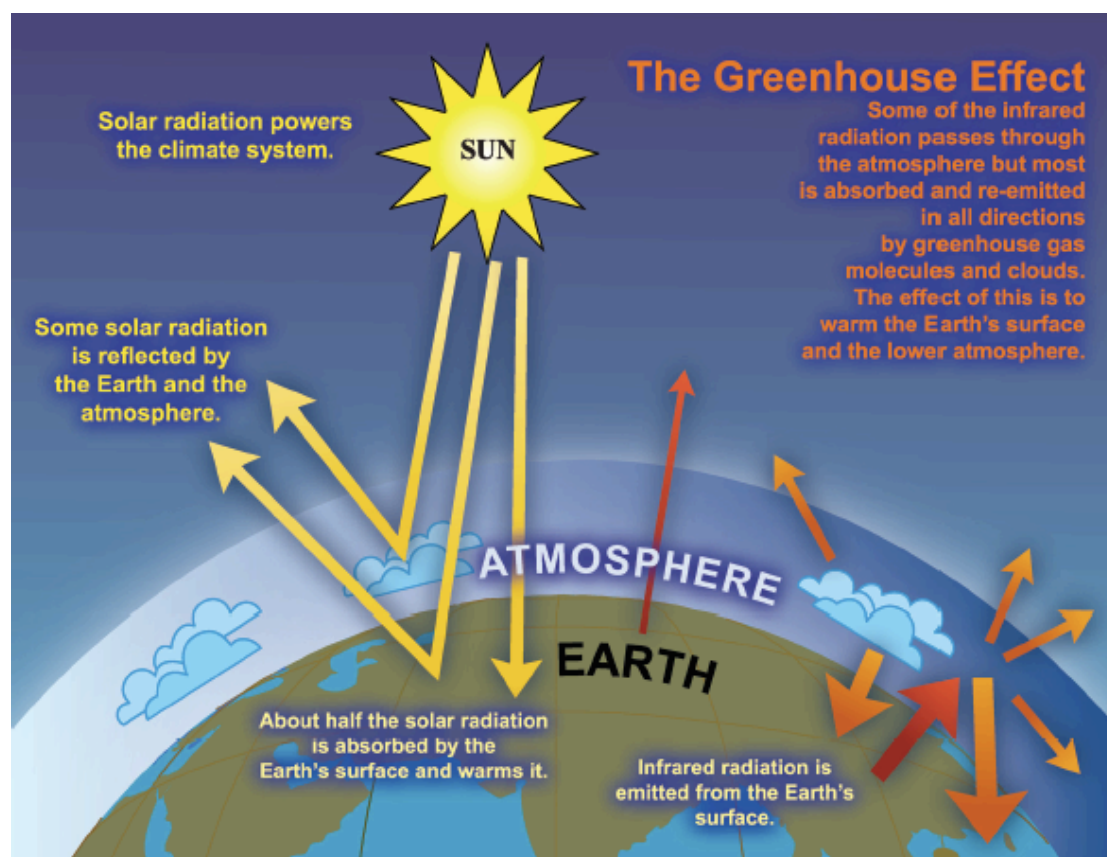


Figure 2-3 The Green House Effect (Source: Le Treut *et al.* 2007)

Figure 2-3 illustrates how GHG now absorb infrared radiations and re-emits it into the atmosphere, and in turn warms the planet. The GHG blanket acts like the glass in a greenhouse, it allows incoming radiation but inhibits the outflow of heat to maintain warmth at earth's surface at 14-15°C, otherwise surface temperature would fall to minus 18°C (Boyle et al. 2003). The most important GHG in terms of global warming potential are water vapour, CO₂ and methane

(CFCs also play a significant role in global warming). Water vapour is controlled by the water cycle with little influence from human activities; however, CO₂ and methane are largely influenced by human activities.

2.3 Key Indicators of Climate Change

The report from the Intergovernmental Panel on Climate Change (IPCC) in 2007 warned that greenhouse gases had already heated the world by 0.7°C and that there could be 5-6°C more warming by 2100, with devastating impacts on humanity and wildlife; It states that:

“Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level”.

The following observed changes are believed to be evidence that climate change is occurring (IPCC, 2007):

2.3.1 Sea Level

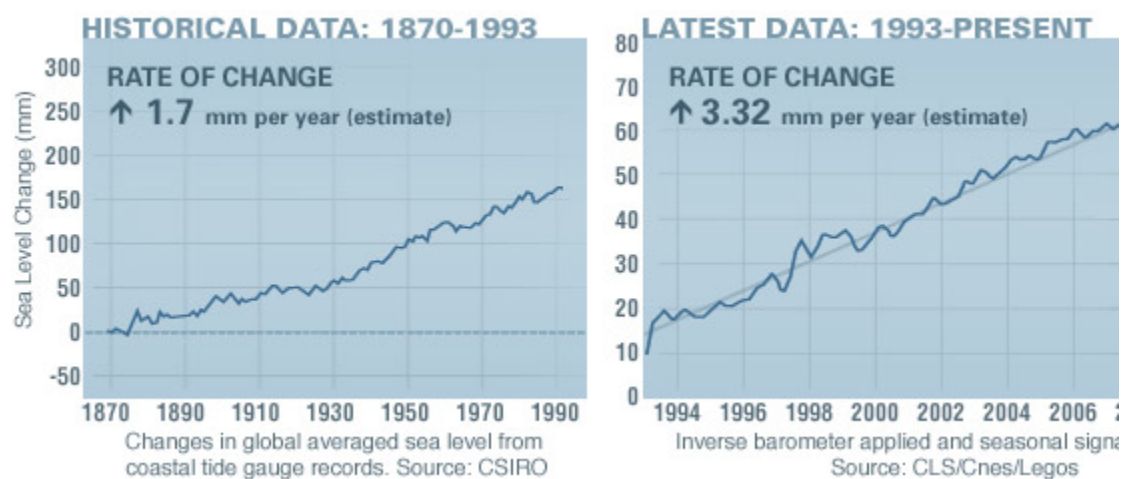


Figure 2-4 Sea Level Data (Source: NASAa 2009)

Historical data since 1870 and until 1993 shows an estimate sea level rise of 1.7 mm per year, this is shown at the left chart recording changes in the global average sea level from coastal tide gauge over the period between

1870 to 1990. The chart on the right side shows data from 1993 and until present time using satellite altimeter³ data, as we can see, the rise of sea level is more drastic at an estimated average of 3.32 mm per year, the data has been updated in January of 2009 (NASA, 2009).

2.3.2 Arctic Sea Ice

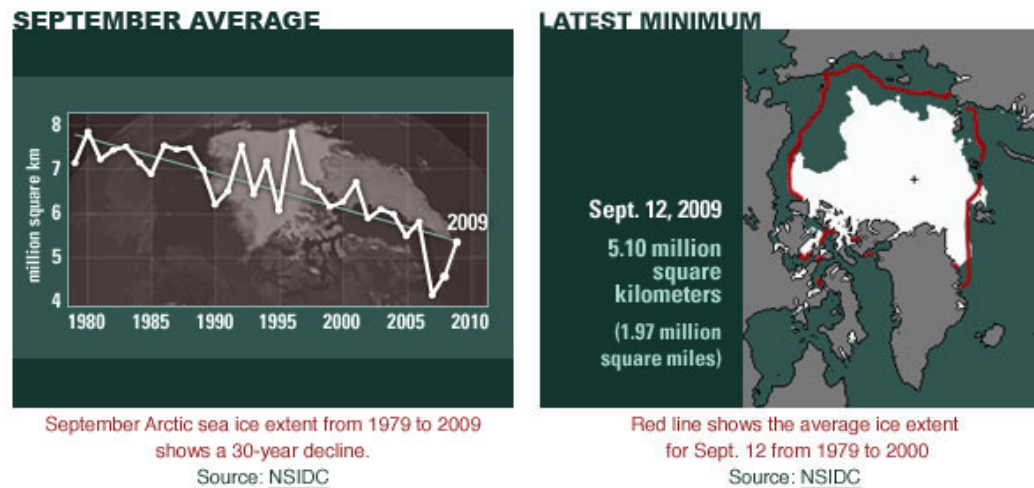


Figure 2-5 Arctic Sea Ice (Source: NSIDC 2009)

In September, the Arctic sea ice reaches its minimum extent, the figure on the left shows the average September extent over the period between 1979 to present. The figure on the right side shows the Arctic sea ice minimum extent which is a third-lowest in the satellite record since 1979 (NASAa 2009, NSIDC 2009).

2.3.3 Carbon Dioxide Concentration

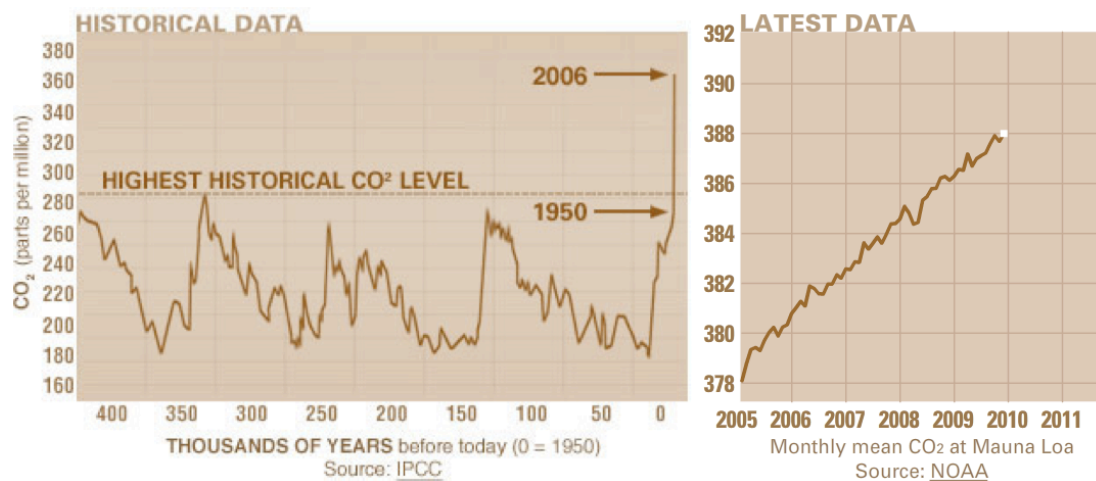


Figure 2-6 Carbon Dioxide Concentration (IPCC 2007 and NOAA 2009 cited in NASAa 2009)

The figure shows the carbon dioxide variations over the last 400,000 years; during which four glacial cycles are recorded at much lower (300 ppmv) carbon dioxide emissions, compared to nearly 400 ppmv today. This data set was recorded from the Vastok Ice Core (IPCC 2007). The figure on the right shows carbon dioxide concentration on the rise since 2005, this data set was recorded by monthly mean level at Mauna Loa (NOAA 2009).

2.3.4 Global Average Temperature

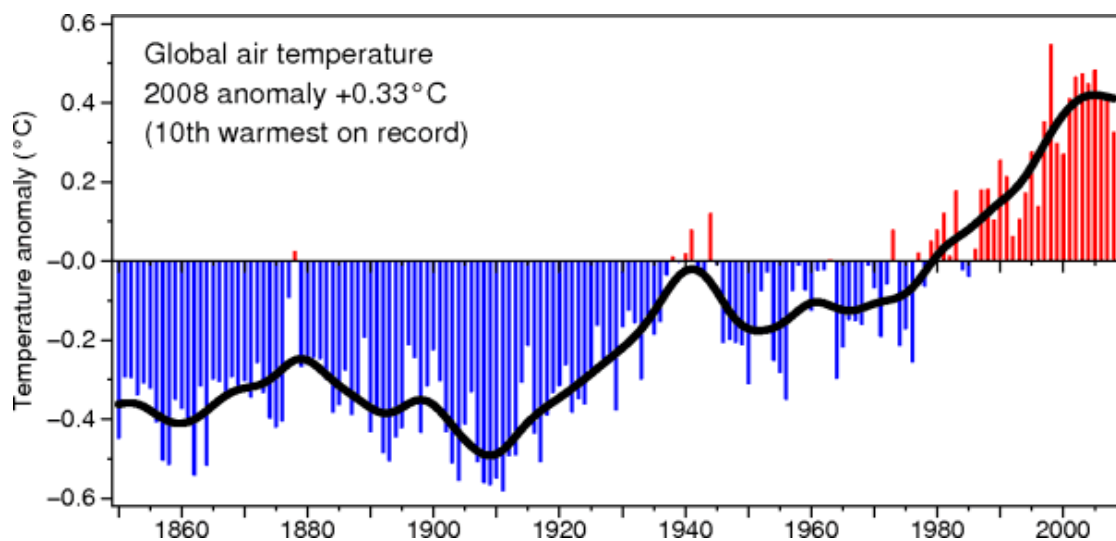


Figure 2-7 Global Air Temperature (Source: Borhan *et al.* 2006)⁴

The figure shows the combined data for global land and marine surface temperature recorded from 1850 to 2008. According to the analysis of over 400 proxy climate series (CRU 2009) the records show that 1990s is the warmest decade of the millennium and the 20th century is the warmest century.

The Intergovernmental Panel on Climate Change (IPCC) states (2007) that “most of the observed increase in global average temperatures since the mid-20th century is *very likely*⁵ due to the observed increase in anthropogenic greenhouse gas concentrations [emphasis in original],” they define ‘very likely’ as at least 90% certain.

Global mean surface temperatures have risen by $0.74^{\circ}\text{C} \pm 0.18^{\circ}\text{C}$ when estimated by a linear trend over the last 100 years (1906–2005). The rate of warming over the last 50 years is almost double that over the last 100 years ($0.13^{\circ}\text{C} \pm 0.03^{\circ}\text{C}$ vs. $0.07^{\circ}\text{C} \pm 0.02^{\circ}\text{C}$ per decade) (Trenberth *et al.* 2007).

⁴ The time series is jointly compiled by The Climatic Research Unit and the UK Met. Office Hadley Centre.

⁵ The term ‘very likely’ is defined by the Intergovernmental Panel on Climate Change as the assessed likelihood of over 90% by expert judgement.

2.3.5 Ozone Hole

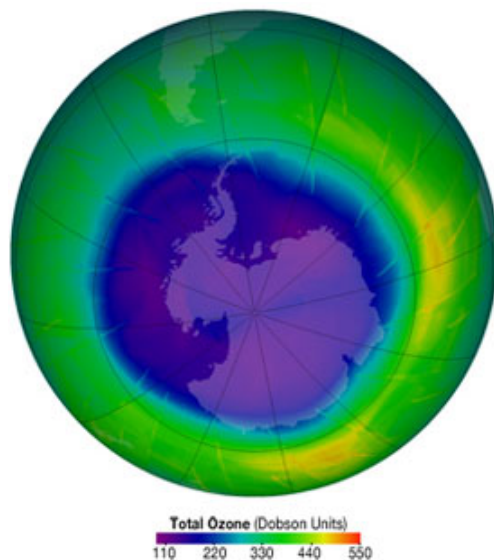


Figure 2-8 Total Ozone showing the Ozone Hole in Dark (Source: NASAa, 2009)

The ozone layer is a protective layer that surrounds Earth and blocks harmful ultraviolet rays from the sun, the Ozone Hole is the depleted ozone located above Antarctica. The current scale of the depletion is shown in the most recent figure shown above, derived from satellite measurements by NASA, the dark colours of blue and purple show the depletion of the ozone layer, whilst the lighter colours of greens, yellows and reds are where the ozone is present (NASAa 2009).

2.3.6 Other Observed Changes

Hurricanes in the North Atlantic have increased in intensity since the 1970s, this increase correlates with the increase in sea surface temperature, other regions have also experienced an increase in hurricanes; such an increase is more likely (>50%) to be due to human contributions, it is likely (>66%) that we will see more hurricane intensity in the 21st century (IPCC 2007).

In addition, there are high confidence (80%) observed changes that are associated with climate change including (IPCC 2007): more and larger glacial lakes, increasing ground instability in permafrost regions, increasing rock avalanches in mountain regions, changes in ecosystems of the Arctic and Antarctic, increased run-off in many glacier and snow-fed rivers, rising water

temperature and changes in ice cover, salinity and oxygen levels and water circulation affecting algae, plankton, fish and zooplankton.

Furthermore, there are very high confidence (90%) observed changes that include (IPCC 2007): spring events happening earlier such as unfolding of leaves, laying of eggs and migration; and shifts in ranges of plant and animal species; as well as that ocean is becoming more acidic (pH dropped by 0.1) due to the uptake of carbon dioxide.

2.4 Projections of Climate Change and its impacts

The world's authority on climate change IPCC's widely cited report of Working Group II (IPCC 2007) presented the following projections of what might be expected to occur in the coming century:

A temperature rise at about 0.2°C per decade is projected over the next two decades, these projections are based on a range of SRES⁶ emission scenarios developed by the IPCC. The report argues that even if concentrations of all greenhouse gases were held constant at year 2000 levels, a further warming of about 0.1°C per decade is expected. Continuation of greenhouse gas emissions at or above current rates would result in further warming and subsequently induce many changes in the global climate system in the 21st century, that are *very likely* to be greater than those observed in the 20th century.

These projections might have the following implications, with varying confidence, each is indicated below (IPCC 2007):

2.4.1 Fresh Water

Changes in precipitation is projected with high confidence (80%) that dry regions will get drier and wet regions will get wetter, drought will increase in

⁶ The IPCC Special Report on Emission Scenarios (SRES) present six scenario groups: A1B, A1FI, A1T, A2, B1 and B2 each one presenting a different rate of economic, environmental and social development – all considered equally sound. For the full temperature and sea level rise for each SRES scenario family.

drought-affected areas, increase of flood risk with expected heavy precipitation, and a reduction in water supplies stored in glaciers and snow covers.

2.4.2 Ecosystems

It is projected with high confidence (80%) that ecosystems' resilience is likely to be exceeded due to climate change and other stressors, and carbon removal by terrestrial ecosystems is likely to peak before mid-century and then reverse – this will amplify climate change.

2.4.3 Food

With a medium confidence (50%), global food production will increase for temperature rises of 1-3°C but decrease for higher temperature ranges.

2.4.4 Coastal systems

Projections with high confidence (80%) that there is an increase in risk of coastal erosion due to climate change and sea-level rises, more frequent coral bleaching events and widespread mortality unless there is thermal adaptation by corals; and increase in floods in the 2080s affecting many millions of people.

2.5 Causes of Climate Change

Although there is no clear acknowledgement in the IPCC (2007) that attribute the above changes to human-induced activities, nevertheless, the report concludes *“with high confidence (90%) that anthropogenic (human-induced) warming over the last three decades has had a discernible influence on many physical and biological systems”*.

The figure below shows the global fossil carbon emissions estimates, it shows how CO₂ has been accelerating since the start of the second industrial revolution in 1850, and more dramatic increases have been recorded since the 1950s onwards. The graph shows fuel types in colours, solids (coal) in blue, liquids (oil) in orange, gasses (natural gas) in dark red, cement in green, and flaring in red – in order of their contribution to total emissions estimates.

The rise in global surface temperature has been attributed to these manmade fossil fuel-generated carbon emissions (IPCC 2001, 2005, 2007).

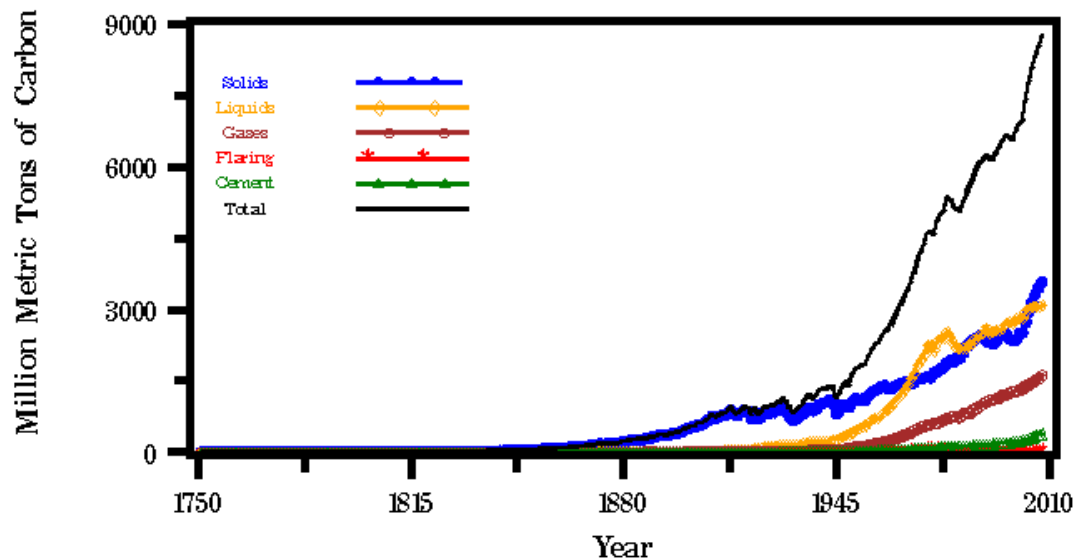


Figure 2-9 Source: Global Fossil Fuel Carbon Emissions Estimates (CDIAC 2012)

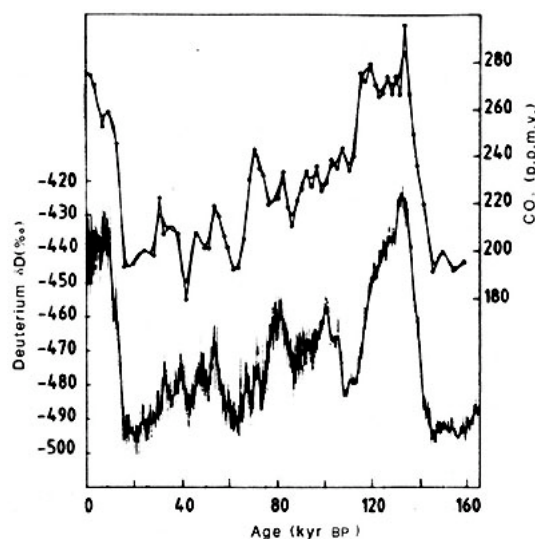


Figure 2-10 Vostok carbon dioxide and temperature curves (Source: Barnola *et al.* 1987 cited in AIP 2009)

The figure above shows two curves, the upper curve plots the CO₂ concentration in parts per million, the lower curve shows the atmospheric temperature from measurements of the isotope Deuterium. Both plotted against age (time) in thousands of years before present, where 0 is present time (AIP 2009). The figure suggests a direct correlation between carbon

dioxide concentration and the atmospheric temperature, where a rise in the former causes a rise in the latter.

2.6 Critics of Climate Change

In his seldom-referenced book, Fred Singer⁷ (1998), a distinguished authority on energy and environmental issues, states that the evidence of climate change is “*neither settled, nor compelling, nor even convincing*”. He argues that climate change is a natural phenomenon and that fluctuations of temperature do not show a general warming trend, but in fact it shows some cooling, he also states that these rises in temperature are not contributed to human-induced carbon dioxide emissions (Singer 1998). Figure 2-7, which shows the global average temperature, in fact shows some slight downward slopping curve i.e. cooling effects rather than warming. This could be seen for example, between 1880-1890 and 1900-1910 and again at 1940-1950 and 1960-1970 as well as most recently 2005-2008. There is no explanation to the ‘cooling’ trends and such arguments have little support in the scientific community; the mainstream explanation is that Earth *has not durably cooled* but undergone global warming in the 20th century (IPCC 2007).

Moreover, Seitz (1998) also backs Singer’s believe, “*we do not at present have convincing evidence of any significant climate change from other than natural causes*”.

In addition, the Nongovernmental International Panel on Climate Change (NIPCC) was established in 2003 by The Science and Environmental Policy Project (SEPP), a nonprofit research and education organization founded in 1990 by Dr Fred Singer. Its activities, as the name suggests, challenges the mainstream climate change advocates, namely, the UN-funded IPCC. The Heartland Institute published a new climate change report for NIPCC entitled “Climate Change Reconsidered”, an 880-page book “*challenging the scientific*

⁷ Fred Signer designed the first satellite instrument for measuring cosmic radiation and atmospheric ozone (SEPP, 2009). He also predicted (1971) that methane is a possible ozone-depleting gas and could contribute to climate warming – this was later confirmed by scientists in 1995 (Seitz, 1998)

basis of global warming concerns that global warming is either man-made or would have harmful effects” (NIPCC 2009).

The NIPCC (2009) argues that the IPCC reports are unreliable, has ‘errors and misstatements’ and has ignored scientific data that were available but inconsistent with the authors’ views. It also criticizes the definitions provided by IPCC to its conclusion, for example, while it defines “likely”, “very like”...etc; it fails to define “most” or explain what does it mean.

The US National Academy of Sciences dedicated a panel to assess the apparent differences in observed at the surface and upper air temperature trends, reported that (NRC 2000: 19):

“The various kinds of evidence examined by the panel suggest that the troposphere actually may have warmed much less rapidly than the surface from 1979 into the late 1990s, due both to *natural causes* (e.g., the sequence of volcanic eruptions that occurred within this particular 20-year period) and human activities (e.g., the cooling of the upper part of the troposphere resulting from ozone depletion in the stratosphere) [emphasis added]”

Hence, the NRC has contributed some of the temperature variations to natural activities.

Furthermore, the IPCC (2007) has warned that rising global temperature will cut West African agricultural production by up to 50% by 2020, however, a recently produced documentary by BBC World Services satellite images over the last 15 years suggest a recovery of vegetation in the Southern Sahara (Yahya 2009). In the same documentary, the Namibian Desert has experienced increased precipitation in 2008 of 80 mm when the average precipitation in the last 60 years has been only 12 mm per year. Dr. Farouk El-Baz, director of the Centre for Remote Sensing in Boston University told BBC World Service in a documentary entitled “The Greening of the Deserts”: *“The heating of the Earth would result in more evaporation of the oceans, in turn resulting in more rainfall”* and therefore shifting the Sahara desert from a dry to a wetter condition (Yahya 2009). This is also possible with the help of

remote sensing and radar imaging from space, these show aquifers, water reservoir trapped underground between permeable rock layers (El-Baz & Ghoneim 2007, El-Baz & Ghoneim 2009).

In fact, some views believe that CO₂ levels are not unprecedented:

“Many people don't realize that over geological time, we're really in a CO₂ famine now. Almost never has CO₂ levels been as low as it has been in the Holocene (geologic epoch) – 280 (parts per million - ppm) – that's unheard of. Most of the time [CO₂ levels] have been at least 1000 (ppm) and it's been quite higher than that,” Happer⁸ told the Senate Committee

“The temperature records cannot be relied on as indicators of global change,” said John Christy⁹, (Leak, 2010). Moreover, “The popular data sets show a lot of warming but the apparent temperature rise was actually caused by local factors affecting the weather stations, such as land development.” Christy said. “We concluded, with overwhelming statistical significance, that the IPCC's climate data are contaminated with surface effects from industrialisation and data quality problems. These add up to a large warming bias,” McKittrick¹⁰ said.

The above critics on climate change remain an issue of debate, however, in this thesis, climate change and its consequential projections are taken as prime motivation of the topic due to the international consensus on the believe that climate change is happening and it is as a result of anthropogenic activities.

2.7 Direct impacts on Saudi Arabia

Saudi Arabia is located in the southwest of Asia, it occupies 80% of the Arabian Peninsula, with a total area of 2,250,000 km² with a total coastline of

⁸ Harper is an award-winning Princeton University Physicist.

⁹ Christy is a professor of atmospheric science at the University of Alabama in Huntsville, a former lead author on the IPCC.

¹⁰ Ross McKittrick is a professor of economics at the University of Guelph, Canada, who was invited by the panel to review its last report.

2,640 km. The climate in Saudi Arabia is described as a “harsh, dry desert with great temperature extremes,” with only 1.65% of the land arable and 0.09% with permanent crops (CIA 2011).

Moreover, in a report by UNDP (2010: 13) Saudi Arabia’s environment is described as “particularly vulnerable to climate change,” the report explains that about 76% of Saudi Arabia’s areas are non-arable lands with 38% being desert. Their impact assessments of the country concluded that most of the country’s regions have “high vulnerability to potential climate change.”

Environmental challenges in Saudi Arabia are characterised by its current climate and nature of its natural resources. CIA (2011) identifies a number of current environmental challenges for Saudi Arabia, which are summarised in the following: desertification, depletion of underground water resources, the lack of perennial rivers or permanent water bodies, the dependence on extensive seawater desalination facilities, and coastal pollution from oil spills.

2.7.1 Sea level rise

According to a study by the Arab Forum on Environment and Development (AFED 2009), the Middle East is assessed as a vulnerable region to climate change. Arab countries, including Saudi Arabia, are to be affected by climate change that is “*projected to induce sea level rise and coastal flooding which will affect human settlements and infrastructure in low-lying coastal areas*” (pg. 90).

Saudi Arabia borders the Red Sea from the West (1,760 km long coastline) and the Gulf from the East (650 km long coastline), more than 50% of the population of Saudi Arabia lives within 100 km of the coast (AFED 2009), and in another reference 30.3% of the population (MPE 2005), including cities, towns, and factories as well as processing plants. The report also discusses the impacts on exports and imports in Saudi Arabia, all of which are based on the coastline, these include desalination plants that supply drinking water in the country, oil refineries and petrochemical refineries, some cement plants as well as the tourism industry (UNFCCC 2005).

Most vulnerable industrial and populated coastal zones to climate change include: Dammam, Ras Tanura, Jubail and Khafji on the East coast, and Jeddah, Rabigh, Yanbu and Jizan on the West coast (AFED 2009). Saudi Arabia's most important city¹¹, Jeddah, is particularly sensitive to climatic change and changing precipitation trends. Magram (2009) provides a review of environmental issues in Jeddah and an analysis of the underlying challenges of the lack of integrated environmental management of its infrastructure, sewage treatment, sewage removal, desalinization plants, flooding and storm drainage and groundwater and lakes. Jeddah's infrastructure problem cannot tolerate excessive amounts of rain and was a partial cause in Jeddah's tragic floods in 2009 and 2010. Moreover, two of the mega projects undertaken in Saudi Arabia are located along the coastline in the Western region, KAUST and KAEC (see chapter 7).

Furthermore, Elasha (2010) explains that precipitation increase which is enforced by climate change will affect Saudi Arabia, the increase in rainfall is projected to *"arrive in concentrated, short and intense precipitation events, which could lead to a higher risk of flash floods and might have negative consequences on aquifer recharge under certain geological conditions"* (pg. 18).

2.7.2 Water and Food

Saudi Arabia has an annual rainfall of only 3-4 inches, Elhadj (2008) argues that since underground water reserves were discovered in the early 1980s, the Kingdom has not used it efficiently, by using non-renewable water resources in irrigating the desert. By 1992 they were irrigating about 2.5 million acres and producing 4.1 million tons of wheat. But by 2000, the average cost of raising wheat in Saudi Arabia rose to \$500 per ton - four times what it costs to buy it on the world market. Elhadj (2008) explains how Saudi Arabia's inefficient use of its natural resources over the decades, especially

¹¹ Jeddah is the main port in Saudi Arabia, it is also regarded as the gate to the holy mosque in Makkah (80 km away with no airport), it also historically lies in an important trade line on the Red Sea, connecting three continents.

water resource, has put the country in a dangerous position. Moreover, Saudi Arabia uses a considerable amount of water for enhanced oil recovery (EOR) and currently faces serious water shortages. The Saudi government has recently announced plans to abandon its food independence strategy and decided instead to import the country's entire wheat needs by 2016 (England and Blas 2008). Therefore, climate change is projected to increase desertification and will precipitate the problem. Reductions in crop production in Saudi Arabia would increase the potential risks of malnutrition and hunger for millions (UNFCCC 2005).

2.7.3 Other projected climatic changes:

Air quality, measured using multiple indicators, is primarily determined by the contribution of different mobile (transportation) and fixed (generators, industry) sources of pollutants. This is further affected by the weather elements including temperature, humidity, and wind. Hence, it is obvious that climate change will have a direct impact on air quality and consequently on the health of exposed populations. On biodiversity, a total of 97 species are said to be threatened by climate change across Saudi Arabia, of which 3 are plants species and 94 are animals species (AFED 2009: 104). On humidity, a decrease in the relative humidity in the range of 1% to 2% in Tabuk and increase 2%-2.5% near Jeddah. Temperature relative increase of up to 4°C for the period 2070 to 2100 in northern and southern parts of the Kingdom during summer, which will have discernable impact. A rainfall, during summer, a 15-20 mm decrease in western coast and northern regions near Tabuk—an increase is expected in the south. Northern and eastern regions will experience drought. Climate change is also expected to contribute in diseases by affecting the seasonal concentrations of some allergens in the atmosphere and therefore causing allergic reactions and pulmonary diseases, also, malaria transmission is expected to peak during rainy seasons and hot summers (AFED 2009).

Figure 2-11 shows stresses on water resources in Saudi Arabia as a result of climatic changes, showing temperature change of 1°C and 5°C and how it

impacts groundwater recharge, irrigation water demands, surface runoff and domestic and industrial water stresses in metric cubic meter or m³ (MCM).

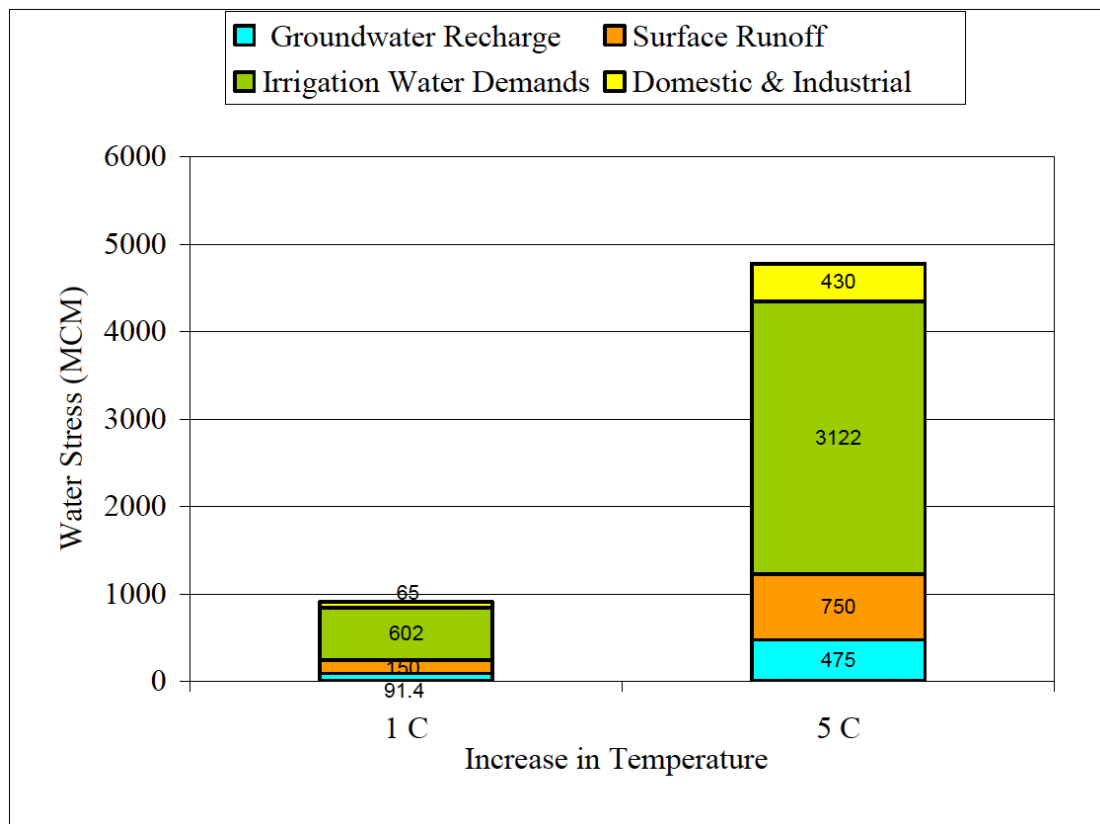


Figure 2-11 Stress on Water Resources as a Result of Climatic Change (Source: Abderrahman 2008)

Potential impacts from temperature increases on Saudi Arabia and the surrounding region in the Arabian Peninsula includes: water shortages, increase soil salinity, reduction of the productivity of rangelands and change of areas amenable to livestock production, change to species composition in favour of woody, less palatable, plants, and an increase in dust and fires (AFED 2009).

In addition, AlZawwad (2008) examined six regions and thirty-seven locations across Saudi Arabia and studied climate change impact where he reiterated water shortages problem in a warming of 2.5°-5.1°C, as well as change of precipitation trends.

Also, Alkolibi (2002) conducted a study to assess the possible impacts of global warming on Saudi Arabia, the cities covered in his study include:

Jeddah and Al Madina in the western province, Riyadh in the central province, and Dhahran in the eastern province.

Moreover, Abderrahman (2008) assessed the possible impacts of climate change on water resources and therefore crop yields, results show projected losses of different types of field crops including cereals, vegetables, and forage crops as well as fruit trees including date palms that range between 5% to more than 25%.

Furthermore, Abderrahman and Al-Harazin (2003) studied the possible effects of climate on the Arabian peninsula, most of which is located in an arid region of the world, including Saudi Arabia's three cities in the East, Central and Western regions: Al-Qatif, Al-Riyadh, and Al-Madina, respectively. Using methods to calculate crop evapotranspiration (mm/day), which combines thermodynamics, aerodynamics aspects, a special computer programme was then used to calculate the changes in values of crop evapotranspiration – this uses data including temperature, humidity, solar radiation, sunshine hours, and wind speed to assess the possible impacts of temperature increases (1, 2, 3, 4 and 5°C). According to the results of the study (Abderrahman and Al-Harazin 2003), the suggested increase in temperature of 1-5°C have a considerable impact on Saudi Arabia's environment, it will decrease soil moisture and increase salinity levels by more than three times. This salinity will affect some species that cannot tolerate high levels of salinity. This is expected to increase the irrigation demands by 1.7 – 20 %, in case these demands were not satisfied the crops will suffer, and some crops species will be damaged partially or completely, enhancing desertification in the Arabian Peninsula.

2.8 Main International Environmental Treaties on Climate Change

2.8.1 Kyoto Protocol

The Kyoto Protocol is an international agreement under the United Nations Framework Convention of Climate Change (UNFCCC)¹² that sets binding targets for 37 industrialized countries and the European community for reducing greenhouse gas emissions (GHG) to their 1990 levels over the period 2008-2012. It was adopted in Kyoto, Japan in 1997 and came into force in 2005; it has been ratified by 185 member countries, with the exception of USA, the highest CO₂ emitter per capita, and the second-highest CO₂ emitter after China (UNFCCC, 1994).

The Kyoto Protocol offers mechanisms through which countries could meet their targets, these are (i) emissions trading or 'the carbon market', *"allows countries that have emission units to spare - emissions permitted them but not "used" - to sell this excess capacity to countries that are over their targets"* (UNFCCC, Article 17, 1994); (ii) clean development mechanism (CDM), which allows countries that are under emission-reduction/limitation commitment to implement emission-reduction project in developing countries; and (iii) joint implementation (JI), allowed countries with emission-reduction/limitation commitment (Annex B) to earn emission reduction units from an emission-reduction/removal project in another fellow Annex B party.

However, since the commitment period ends in 2012, there is a need for a new international framework for climate change mitigation beyond 2012

2.8.2 Bali Roadmap

The Bali Roadmap is a framework for climate change mitigation beyond 2012, which started in 2007 as a two-year process to finalise binding agreement in Copenhagen Summit of 2009. At the summit, however, countries stated what

¹² The UNFCCC was agreed to be established in the Earth Summit in Rio de Janeiro and entered into force in 1994 and has been ratified by 192 member countries.

actions they were proposing if a binding agreement was achieved but no such agreement was reached and instead was deferred to a future date.

2.9 Islamic Principles and Saudi Arabia's stance on climate change

Saudi Arabia rules by the religion of Islam, it is integrated in its constitution and other policies; also, the religious establishment plays a key role in influencing policy (see Chapter 3).

Swazo (2010) explains Islamic principles that perhaps defines Saudi Arabia's ideological stance on climate policy, he summarises conclusions:

(1) the government acknowledges the rights of future generations; (2) it is sufficiently concerned about global climate change and reasonable mitigation measures on greenhouse gas emissions; but that (3) it is also reasonably concerned to safeguard the rights of future generations of Saudis according to what, in international treaty, is recognized as declared standards of justice, viz., those stipulated in the UNFCCC and KP principles governing common but differentiated responses among the international community; further, (4) sustainable development of the Saudi economy remains an unquestioned and reasonably defensible commitment; the government recognizes that such development entails (5) diversification measures far beyond its present financial and technological capability; hence, (6) the argument for compensation is itself reasonably grounded in the context of international negotiations for climate change mitigation.

There is a thin literature on Saudi climate policy, however, Depledge (2008) provides a comprehensive and critical report on the Saudi position. It argues that Saudi Arabia [understandably] is concerned about its [oil-based] economic development in a seemingly increasing carbon-constrained future. The report concludes that Saudi Arabia is perceived as an 'obstructionist' in international environmental negotiations (Depledge 2008).

On the one hand, Saudi Arabia's statement to the UN for addressing climate change shows much commitment and willingness of cooperation as well as

collaboration in international environmental negotiations (Tayeb 2007, Al Naimi 2008).

On the other hand, in Saudi Arabia's tireless pursuit to maintain a delicate balance between its oil-based economic development and think efforts in climate policy, its reputation may have been tainted as fiercely argued by Vihma (2011): *"long-time obstructionist Saudi Arabia thrives on the procedural conflicts, and is clever at utilizing the political space that opens up when big players are in disagreement. Saudi Arabia is specialized in provoking conflicts in the inter-sessional meetings, while staying out of the media spotlight."*

According to the latest report of Climate Change Performance Index (Burke 2011), Saudi Arabia was ranked last, number 60, in climate change performance, scoring 25.8 (highest grade 70.5); The ranking considered emissions trend (50% weighting), emissions level (30% weighting) and climate policy (20% weighting).

In addition, Saudi Arabia has been grouped amongst countries with 'worst emissions trends' measured over the last five years (Burke 2011: 10), the Kingdom also ranked the lowest in climate policy, it received an overall grade of "very poor" for its climate change performance: *"as evident by its extremely high emissions levels and trends and lack of positive policy approaches, Saudi Arabia remains a considerable part of the problem"* (pg. 15).

However, one of the major targets of the basic environmental strategy of the Kingdom of Saudi Arabia is the conservation of biodiversity and the protection of wildlife in order to maintain ecological equilibrium, particularly with respect to rare, vulnerable and endangered animal and plant species. This key aspect of the national environmental policy has been further reinforced through the signing by Saudi Arabia of the international Convention on Biological Diversity (CBD). In addition and despite the fact that the Saudi economy depends largely on oil, the Kingdom has spared no efforts to address global environmental issues such as climate change. The Kingdom of Saudi Arabia ratified the United Nations Framework Convention on Climate Change (UNFCCC) in 1994 (UNDP 2009).

Moreover, Saudi Arabia is a party to a number of international agreements, including: Biodiversity, Climate Change, Desertification, Endangered Species, Hazardous Wastes, Law of the Sea, Marine Dumping, Ozone Layer Protection, Ship Pollution (CIA 2011).

3 The Saudi Arabian Economy and Its Energy Sector

This chapter provides a background on the case study of Saudi Arabia. First, a profile of the country is presented, then the importance of Saudi Arabia in the world economy is established, an overview on the Saudi energy sector is provided followed by an analysis of economic development with a focus on energy. The chapter ends with a summary on Saudi efforts for combating climate change is provided, and a summary of the challenges facing Saudi Arabia.

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- 3 The Saudi Arabian Economy and Its Energy Sector
 - 3.1 Introduction
 - 3.2 Country profile
 - 3.3 The Importance of Saudi Arabia in the World Economy
 - 3.3.1 World's Energy Superpower
 - 3.4 The Energy Sector
 - 3.4.1 Short History of Institutional Arrangement
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 - 3.5.1 Stage I: The discovery of an Oil State (1932-1950)
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 - 3.5.7 Political System
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 - 3.6 Sustainable Energy in Saudi Arabia
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 - 3.6.2 Renewable Energy Exploitation
 - 3.7 Conclusion

3.1 Introduction

Chapter 2 provided a thorough overview on climate change and challenges facing Saudi Arabia, this chapter provides a background on the case study of Saudi Arabia. It starts with a brief country profile then establishes the importance of Saudi Arabia in the world economy. It then provides a brief discussion on Saudi's economic development and energy sector.

3.2 Country profile

Saudi Arabia is located in southwest Asia at the intersection of three continents, Europe, Asia and Africa. Saudi Arabia's borders include the Red Sea on the west and the Arabian Gulf on the east; Jordan, Iraq and Kuwait in the north, Yemen and Oman on the south, and the United Arab Emirates, Qatar and Bahrain on the east.



Figure 3-1 Map of Saudi Arabia (Source: Maps.com 2011)

Saudi Arabia is a large country with a total area of 2,149,690 km² (CIA 2010), home to the world's "largest continuous sand desert" – *Al Rub' Al-Khali*, the Empty Quarter (OPEC 2010), and a population of nearly 25 million (MEP

2009; IMF, 2009; OPEC, 2010; World Bank, 2010). Saudi Arabia's economy is heavily dependent on oil as it accounts for 90% of the Kingdom's exports and 45% of its GDP (OPEC 2010; Bureau of Near Eastern Affairs 2010).

The figure below shows the growth of the overall economy and its direct dependence on the growth of the oil sector. It presents the growth of macroeconomics and oil sector for the period 1971-2005, five-year moving average (fixed prices of 1999), according to the source.

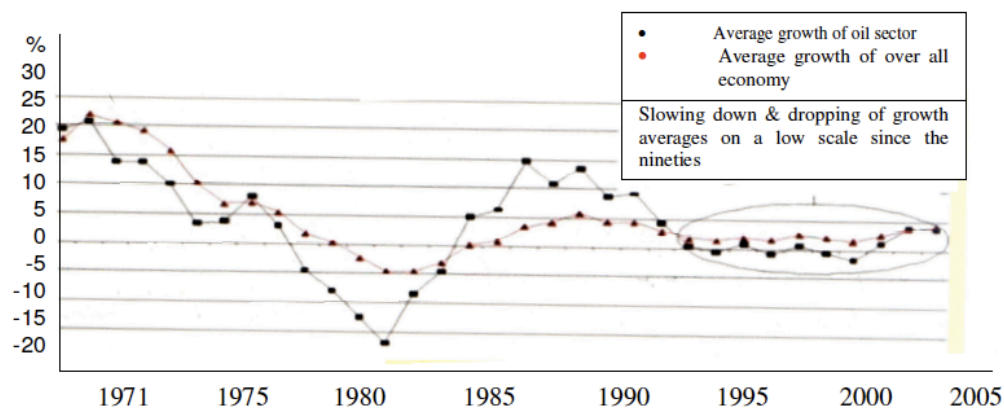


Figure 3-2 Growth of macroeconomics and oil sector for the period 1971 - 2005
(Source: MEP 2007)

The figure shows the two intertwined graphs of the average growth of the oil sector (black) and the average growth of the overall economy (red). It could be seen, particularly in the last decade, that both graphs are positively correlated. The Kingdom's economy is heavily dependent on oil, which accounts for 45% of its GDP and 90% of its exports, some non-oil exports are also oil-based, including but not exclusive to: plastics, petrochemicals and metals (MEP 2010; OPEC 2010; Bureau of Near Eastern Affairs 2010).

3.3 The Importance of Saudi Arabia in the World Economy

The role of Saudi Arabia in the world economy stems from it being the world's *de facto* leader of energy, in terms of proven oil and gas reserves (BP 2010). Saudi Arabia's leadership role in the Middle East region also adds to its significance, a region endowed with nearly half the world's oil proven reserves. Saudi oil fuels the world's two largest economies of USA and Japan as well as the two fastest developing economies of China and India. These

four national economies together with South Korea are the top consumers of Saudi oil (BP 2010). The importance of Saudi Arabia stems from three main roles which influences the world economy, these are:

3.3.1 World's Energy Superpower

According to the latest BP Statistical Review of World Energy (2010) Saudi Arabia sits on the world's largest oil reserves¹³, estimated at 264.6 billion barrels, the equivalent of nearly 20% of the world's proven oil reserves. In a fossil-fuel dependent world¹⁴, Saudi Arabia is likely to remain a world's leading oil producer and exporter in the foreseeable future. Saudi Arabia also owns the world's fourth largest gas reserves estimated at 275 trillion cubic feet (Tcf), half of which is associated with oil deposits (EIA 2011), as well as an abundance of direct sunlight creating a massive solar energy potential.

Table 3-1 shows proven oil reserve as a percentage of total production of the world's total, starting with Saudi Arabia, the Gulf Cooperation Council (GCC¹⁵), the Middle East, the Organization of Petroleum Exporting Countries (OPEC) and the world, all shown as a percentage of total reserves.

Table 3-1 Proven Oil Reserves as a percentage of world's total (Source: compiled by author data from BP 2010)

	Barrels	Percentage
Saudi Arabia	264.6	19.8%
GCC	608.96	45.7%
Middle East	754.2	56.6%
OPEC	1,029.4	77.2%
World	1,333.1	100%

¹³ Venezuela has surpassed Saudi Arabia in proved reserves in 2010 (OPEC 2011)

¹⁴ See Figure 1 in Chapter 3 for the current fossil fuel-dependence of world's primary energy production (BP 2009)

¹⁵ The GCC comprises of the countries that overlook the Arabian Gulf and share almost similar economic, political and social background, these are: Saudi Arabia, Kuwait, United Arab Emirates, Oman, Qatar and Bahrain. Recently, however, (May 2011) Morocco was invited to join and Jordan has asked to join the council. As this development comes in the time of Arab Spring, revolutions starting in Tunisia and Egypt, it appears to be an act of protection of monarchy governments against uprisings.

In a book section by Cordesman and Obaid (2005), Saudi Arabia's importance to energy security is defined in its oil reserves and production, OPEC leadership as a swing producer, and having the largest spare capacity (pp. 309-10). Moreover, Saudi Arabia's leadership in the region adds to its significance and could be explained as follows:

3.3.1.1 The Gulf Cooperation Council

Saudi Arabia is regarded as the leader in the Gulf Cooperation Council (GCC), which was created in 1981, and brought together 'the oil-rich dynastic kingdoms of the Gulf' for common strategic and ideological concerns in the face of Iran and Iraq (Pinfari 2009, p. 4). Because of Saudi Arabia's top spending on security, Cordesman and Obaid (2005) argue that Saudi Arabia enjoys a leadership role in the GCC and therefore an integral role for its stability. There are three main fronts from which Saudi Arabia GCC leadership stems: first, from a security perspective, the Saudi-led force, Peninsula Shield Force (PSF, mobilised in the aftermath of Gulf War I (1984), to protect and deter any external military aggression or threats to the GCC members¹⁶. Second, from a demographic perspective, in 2009 Saudi total population was 25 M, which was equivalent to 67% of the 37 million total population of the entire gulf (GCC 2010, p. 11), third, from an economic and financial perspective, in 2009, daily production of oil constitutes 56% at 8,184 thousands barrels per day out of the GCC total of 14,452.8 thousands barrels per day (GCC 2010, p. 25). Electricity production in Saudi Arabia is the top amongst GCC, in 2009, electricity was reported at 186,725 million kWh, around 60% of the total 307,968.2 million kWh of the entire GCC (GCC 2010, p. 26). Water production (desalination) reported top in Saudi Arabia at 465 billion gallon in 2009, 42% of 1,095.2 billion gallon in the entire GCC (GCC 2010, p. 26). In gross domestic product (GDP), Saudi Arabia's 2009 figure

¹⁶ More recently, the PSF was used in Bahrain for the crackdown of protestors, as the wave of what has become known as The Arab Spring (2011) reached Saudi Arabia's neighbouring state.

recorded \$375,766 million, 41% of the total \$897,963.3 million of the entire GCC (GCC 2010, p. 32). In gross national product (GNP), Saudi Arabia in 2009 recorded \$384,379 million that is 40% of the total 862,922.9 of the entire GCC (GCC 2010, p. 34). Saudi Arabia also tops its members in government budget constituting 50% of the entire GCC in 2007 (GCC 2010, p. 35), and domestic liquidity at \$1,028,943 million that's 47% of the total \$2,161,793.8 million (GCC 2010, p. 38).

3.3.1.2 Islam

Saudi Arabia's leadership role stems also from its religious significance of being home to Islam's two Holy mosques¹⁷ and hence a leader, in that regard, to the Muslim and Arab world. The Holy city of Makkah¹⁸ is the birthplace of the Prophet of Islam, Prophet Mohammad (peace be upon him) and is regarded as Muslims' holiest place where the message of Islam has started. Today, Makkah is the capital of the Muslim world and remains the direction of prayer (*Qiblah*) for Muslims across the world and is home to Muslims' first Holy Mosque (*Almasjid Alharaam*). Also, Medina, the city of the Prophet and the first Muslim state, it is the city that embraces the Holy Mosque of the Prophet (*Almasjid Alnabawi*), and His former house that he has inhabited, and which forms his grave where he is now buried, peace be upon him.

Saudi Arabia welcomes hundreds and thousands of visitors throughout the year for religious obligations and spiritual experiences at the two Holy Mosques. During high seasons, namely in the months of *Ramadan*¹⁹ (9th month of the *Hijri*²⁰ year) and *Thulhijja*²¹ (12th and last month of the *Hijri* year),

¹⁷ There are three Holy mosques in Islam, *Almasjid Alharaam* in Makkah and *Almasjid Alnabawi* in Medina, Saudi Arabia and *Almasjid Alaqsa* in Jerusalem, occupied Palestine.

¹⁹ Fasting Ramadan is the fourth (out of five) pillar of Islam which must be fulfilled to complete one's Islam religion

²⁰ *Hijri* stems from Arabic word *Hijra* (literally, immigration) which refers to the emigration of Prophet Mohammad, and his followers, from Makkah to Medina in CE 579, this makes it the first Muslim state and marks the start of the *Hijri* year of the Muslim calendar. The year CE 2010 corresponds to the Hijri year 1431 AH (after Hijra).

Saudi Arabia embraces millions of visitors and pilgrims from across the world to perform pilgrimage (*Omra* and *Hajj*) in Makkah and who also often precede it with visits to the Holy mosque in Medina. It issues visas and provide security and organisation for a pleasant stay over the duration of their trip. Such a period also forms the electricity consumption peak in the Kingdom as will be discussed later. Hence, Saudi Arabia is given some form of leadership, control and influence over many Muslim states.

With such grand religious and spiritual significance, of a fastest-growing religion in the world (WCE 2005) with at least a growing number of 1,188,242,789 Muslims²² making up nearly 20% of the world population (WCE 2005, Britannica Encyclopaedia 2005, CIA World Factbook 2008), Saudi Arabia holds upon it the responsibility of protecting and *serving* these two²³ Muslim Holy lands, Makkah and Medina. The ruler of Saudi Arabia's official title is the Custodian of the Two Holy Mosques, a title first endorsed by late King Fahad bin Abdulaziz (ruled from 1983-2005), the title was later inherited with the throne by the next ruler in line, King Abdullah bin Abdulaziz, the current King of Saudi Arabia.

3.3.1.3 Middle East

Another regional importance of Saudi Arabia stems from its [relative] economic might and oil-derived power within the Middle East in world economy is that the entire region holds about half the world's reserves (Table 3-1). Saudi Arabia has the highest GDP in the MENA region, as shown in

²¹ *Hajj* (pilgrimage), which is performed in the month of *Thulhijja* is the fifth (and final) pillar of Islam to complete and fulfil a Muslim's religion, the first four being: the *shahada* (Islamic creed), daily five prayers, fasting during *Ramadan*, and *Zakat* (almsgiving).

²² Whom often wish to visit Islam's holiest lands (in Saudi Arabia) at some point in their lives, sometimes more than once.

²³ Muslims have a total of three Holy Mosques to which they are permitted to travel to and seek refuge in; in addition to the two Holy mosques of Makkah and Medina, the third is is Al-Aqsa mosque in Jerusalem, occupied Palestine and known as *al-masjid al-aqsa*. Whose governance has been overtaken by force under Israeli authority over the past five decades, since the beginning of the Palestinian-Israeli war

figure 3-3 below, and its electricity system is the largest in the Arab world, with peak loads in 2008 reaching 37,152 MW (ECRA 2009).

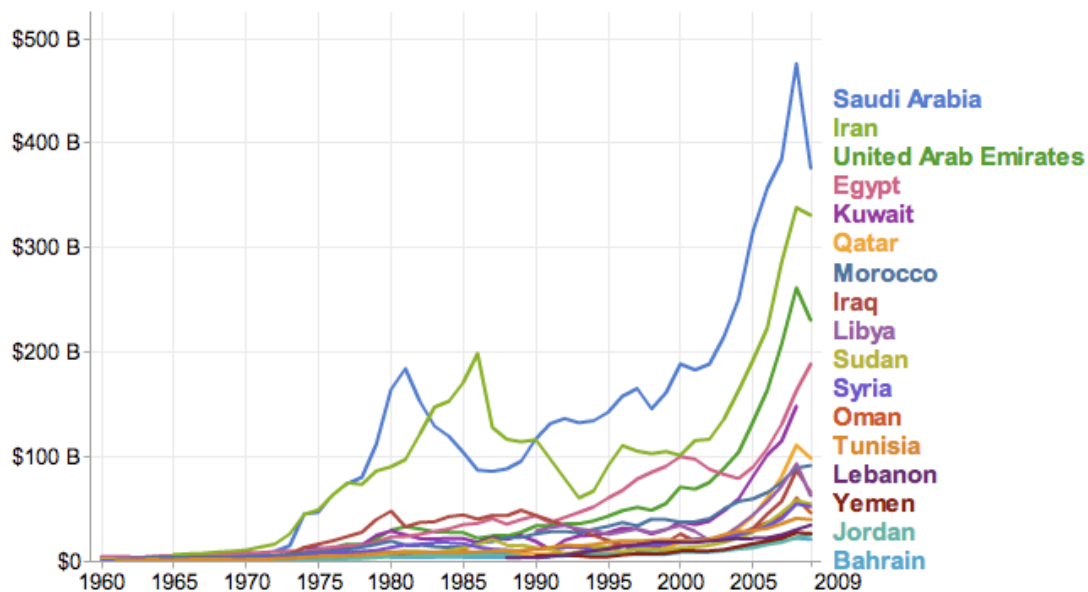


Figure 3-3 Gross Domestic Product, in current U.S. dollars not adjusted for inflation (Data source: World Bank, World Development Indicators through Google service 2011)

3.4 The Energy Sector

Over the last seven decades, the energy sector has been driven by a growing population, expanding cities, infrastructure building and development and more recently a booming construction sector. The evolution of the energy sector could be easily followed through the timeline of energy demands presented in the figure below.

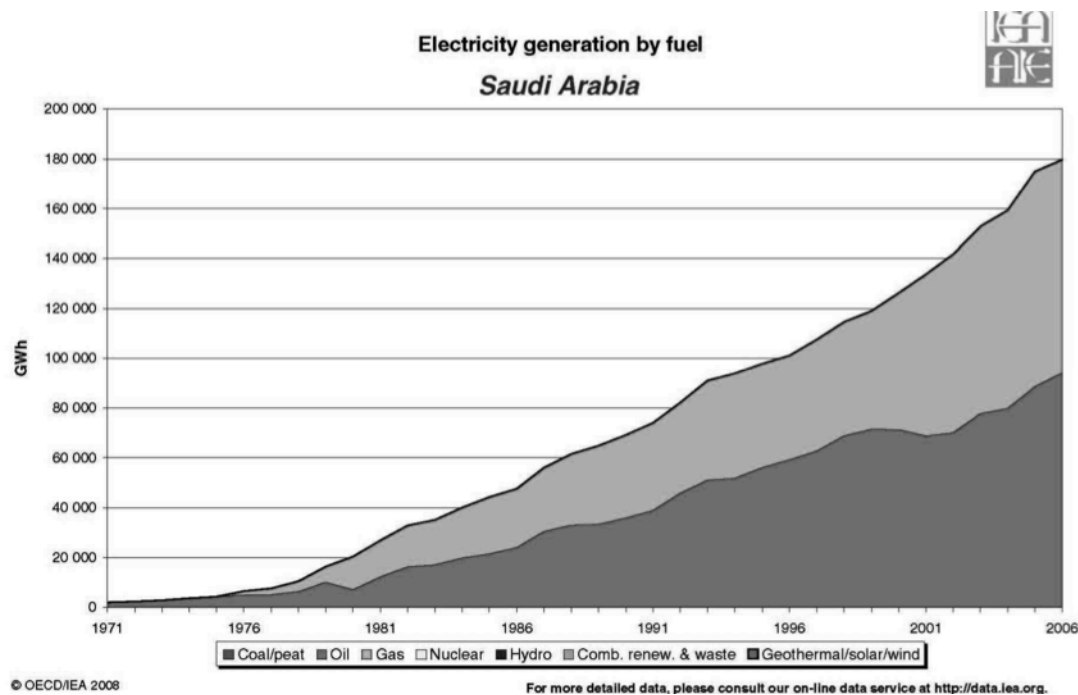


Figure 3-4 Electricity Generation in Saudi Arabia (1971-2006) (Source: IEA/AIE 2008)

The figure shows electricity generation in Saudi Arabia since 1971 to 2006. Starting at near zero and growing massively over the decades, the top wedge represents gas and the bottom wedge represent oil.

The Kingdom today continues to rely on crude (CR) for its electricity generation; it is used as the basic fuel for gas turbines (KFUPM 2006a) this is due to the adequacy and ease of availability of CR relative to that of natural gas (NG). CR has heavily fuelled electricity generation in the Kingdom of Saudi Arabia since the inception of its oil industry. However, since the 1970s NG has increasingly become another source for electricity generation, before which it has been flared in the air wasting an invaluable natural resource and also contributing to a growing cumulative CO₂ emissions level.

Therefore, as an oil-based economy, the Kingdom expectedly ranks high in CO₂ emissions which will likely continue to be at the present rate if no carbon emission reduction technologies are introduced, and it will further increase if future electricity demands are met using the existing fossil fuel technologies with no alternative energy technology generation to be pursued. Hence, carbon management technologies present an unrivalled opportunity for the

Kingdom to both sustain its oil-rich economy and a growing oil-based power generation by addressing its carbon emissions and climate change problem as well as contribute in its transition towards sustainability (as shall be seen in the following chapters).

The Saudi electricity generation is expected to more than double by 2025 due to a growing population, which is expected to grow at an average growth rate of 0.86% up to year 2025 (MEP 2005). Energy needs in the Kingdom are growing at an unprecedented rate also due to the industrialisation of its cities and the development of further new industries and cities for continued industrialization and urbanisation.

Saudi Arabia aspires to become a 'developed, thriving and prosperous economy by 2024' according to its LTS 2025 long-term strategy (MEP 2005; UNDP 2007) as part of the strategy, the mega projects of seven new economic cities have been announced most recently, two are under construction and one is near completion, the King Abdullah Economic City in Thuwal (Close to Jeddah Port) its university, King Abdullah University for Science and Technology, is running since Fall 2009 (See KAEC 2010; KAUST 2010). Urbanization could be measured by looking at the population influx into main cities like Riyadh, the capital, starting with 7,500 in 1862 and booming more than 26 times to 169,000 after a century, growing to 1.5 m in 1982 to 2 m in 1986 and finally reaching 5.8 m in 2006 (SaudiInf 2010).

3.4.1 Short History of Institutional Arrangement

Today, the energy utility sector in Saudi Arabia is managed by two main authorities: (1) the Saudi Ministry of Water and Electricity (MOWE), which establishes the overall policies, plans and strategies for the industry, and (2) the Electricity and Cogeneration Regulatory Authority (ECRA), which regulates the industry and issues licenses for electricity generation and water desalination activities across the Kingdom, such licenses are issued to entities like the Saudi Electricity Company (SECO) and the Saline Water Conversion Corporation (SWCC) and other institutions in the industry.

There are two industries under the energy sector: (i) the electricity industry, dominated by SECO, it is a joint public stock company with 81% ownership by the government and Saudi Aramco and (ii) the water desalination industry, under which the government agency SWCC is the only significant player. Different institutions govern the oil and gas industry in Saudi Arabia, mainly: The Ministry of Petroleum and Mineral Resources and the state-owned oil company Saudi Aramco. (See the following section on Saudi oil policy)

3.4.2 Energy Generation

The energy generation capacity in the Kingdom in 2007 reached 37,154 MW (ECRA 2008) it is expressed in the following table and broken down by producing entities, their share from the total number of plants, and the generation capacity in Mega Watt (MW) by each entity (ECRA, 2008):

Table 3-2 Saudi Generation Capacities (Source: ECRA 2008)

<i>Producing Entity</i>	<i>Number of Plants</i>	<i>Capacity (MW)</i>
Saudi Electricity Company (SEC)	49	30,670
Saline Water Conversion Corporation (SWCC)	12	3,426
Saudi Aramco	5	834
Tihamah Power Generation Co.	4	1,074
Marafiq (Yanbu)	1	900
Jubail Power Co.	1	250
Total	72	37,154

The main supplier of energy is SEC, producing around 80% of the total capacity. The composition of fuels in energy generation is oil and gas, with the latter playing an increasingly important role. The use of natural gas has become increasingly important since the mid 1980s (CDIAC 2009). During the 1970s, natural gas used to be flared in the air – contributing to carbon emissions. New technologies have helped the country make use of natural gas in refining as well as injecting it (CDIAC 2009). Today, it makes up 52% of the electricity production fuel types as shown in the pie chart below.

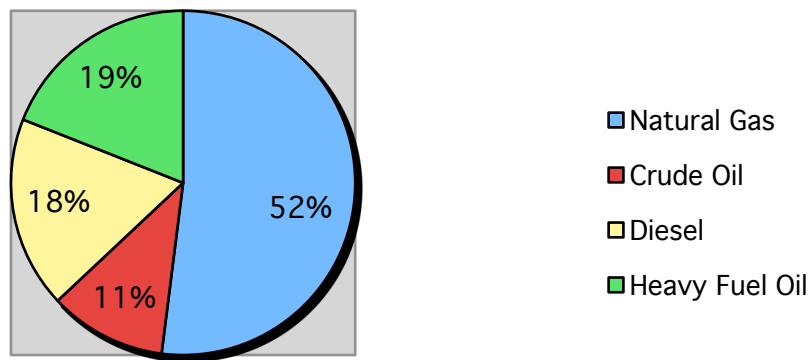


Figure 3-5 Fuel types used in Saudi electricity production in 2007 (Source: data from ECRA 2008)

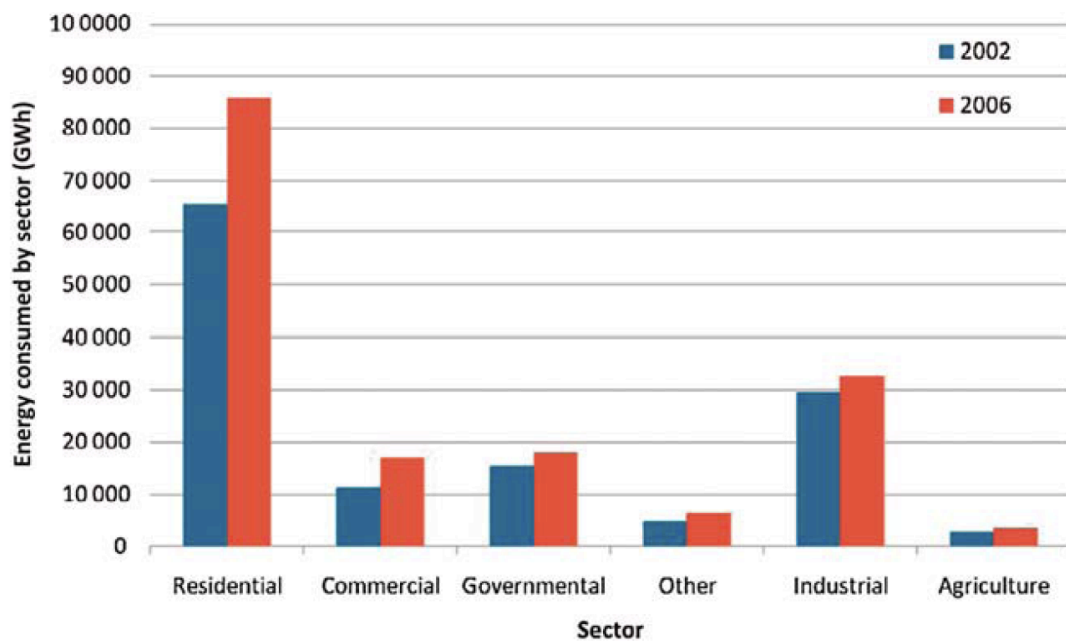


Figure 3-6 Energy Consumption by Sector in Saudi Arabia in 2002 and 2006 (Source: Alyousef and Vernham 2010)

Figure 3-6 shows the trends in energy consumption by sector as a comparison between 2002 and 2006, showing growth in all sectors. Electricity consumption by the residential sector is the highest, followed by the industrial sector, and then governmental, commercial and agriculture.

3.4.2.1 Electricity Projections

Electricity projections are directly related to population growth as well as economic development, construction, urbanism, and other economic development indicators. The following graph from ECRA's Annual Statistical Report (ECRA 2009) shows actual consumption reaching 170 TWh in 2008. Projected consumption is expected to reach 270 TWh by 2015 (ECRA 2009).

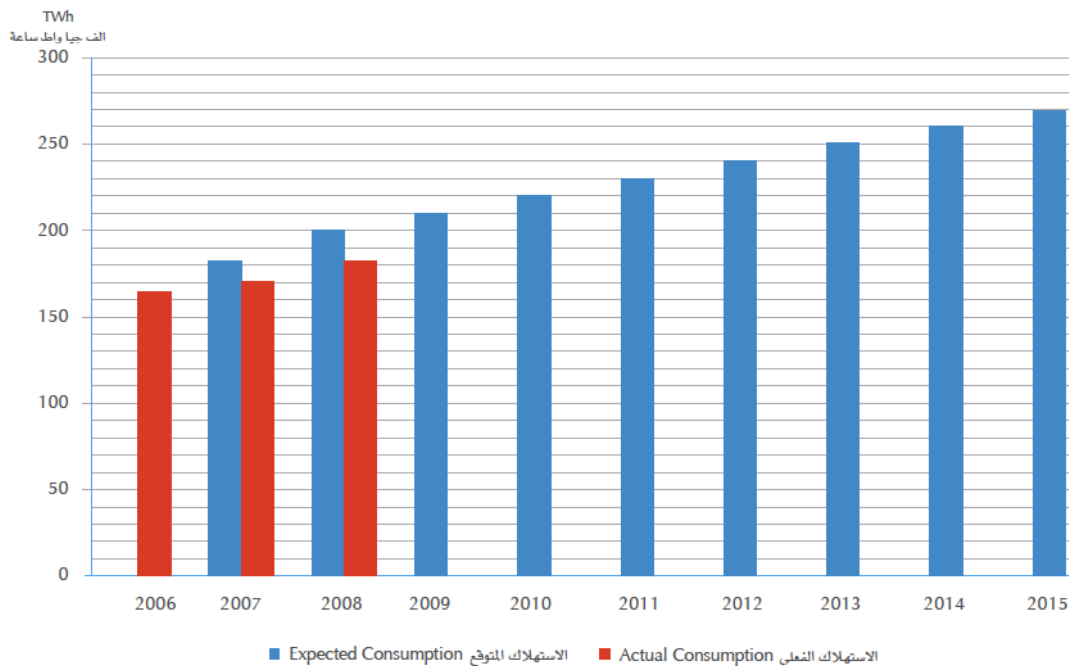


Figure 3-7 Forecast of Electricity Consumption in Saudi Arabia for the period 2006 - 2015 (Source: ECRA 2009)

3.4.3 Carbon Dioxide Emissions

The Kingdom ranks 21st in countries with the highest CO₂ emissions per capita in 2006 (Nation Masters 2011), CO₂ emissions per capita have grown ten-fold since 1950, today the figures are well above the global average which is at 4.38 metric tons of carbon per person (Boden *et al.* 2009). In terms of total CO₂ emissions, Saudi Arabia ranks 16th globally at 438.25 million metric tonnes of carbon dioxide (2008 data, EIA 2010a), however, this is only 4.6% of the world's largest emitter the USA (WRI 2003).

Moreover, Saudi Arabia's estimated GHG emission as calculated by MEP (2005) includes a contributed 90% of the total CO₂ emissions by the energy sector, followed by the industrial processes sector (8%) and the agriculture

sector (2%); Major source categories contributing to these CO₂ emissions (contributions ≥ 2% of the total emissions) were electricity generation (26%), road transport (25%), desalination (15%), petroleum refining (10%), cement production (5%), cement industry (3%), petrochemical industry (3%), aviation (3%) and iron and steel production (2%).

The flaring of gas in the oil fields in the early 1970s contributing to fossil-fuel emissions accounted for 76%. After incorporating new technologies in the oil industry, allowing the refining of natural gas or reinjection – flaring dropped to a striking figure of less than 1% of today's total emissions (Boden *et al.* 2009).

Therefore, it is clear that the major source of CO₂ emissions in Saudi Arabia comes from fossil fuel-powered power plants, which generate electricity energy and water desalination to satisfy the ever-increasing energy and water demands of a growing population.

3.5 Economic Development

Transition has characterised economic development in the Kingdom of Saudi Arabia since its inception:

“Early in 1933...Saudi Arabia was an isolated and little-known desert country, and in its eastern province, where the concession area lay, the population had had few contacts with the outside world and had little or no familiarity with modern technology... Forty-some years later, Saudi Arabia had become an international financial powerhouse, with the world's largest oil reserves and a well-educated and sophisticated population” (Brown 1999)

Saudi Arabia's economic development can be generally described in the following stages:

3.5.1 Stage I: The discovery of an Oil State (1932-1950)

The unification of the modern²⁴ Kingdom of Saudi Arabia by King Abdulaziz Al Saud was declared on September 23, 1932. Population was mostly nomadic

²⁴ The first Saudi state was established in 1744-1818, the second Saudi state lasted until 1891, and later the third Saudi state established in 1932 became known as modern Saudi Arabia.

and activities were exclusive to agriculture. Saudi Arabia was virtually a penniless country (Long 1979), soon after the discovery of oil, American explorers helped establish the oil and gas industry, the advent of the Saudi-US diplomatic relations defined the beginning of the oil era for Saudi Arabia.

Oil was discovered in neighbouring country [on the East border] Bahrain in 1932 by Standard Oil of California (SOCAL, today Chevron), which soon started negotiations with the Saudi government for oil exploration in its East coast. The following year, Saudi Arabia granted oil concession to California Arabian Standard Oil Company (CASOC), an affiliate of SOCAL/Chevron. The company was 50% acquired by Texas Oil Company (Texaco, now Chevron) in 1936. After four years of tireless, albeit fruitless, exploration, the first commercial oil field was discovered in 1938, Dammam number 7 and soon oil export started in 1939.

The Standard Oil Company of California received a concession to search for oil in the Kingdom of Saudi Arabia in 1933, together with Texas Company (Texaco), the two oil companies were responsible for producing and marketing oil from the first Saudi oil well (Vitalis 2009). The US-Saudi relations have shaped and been shaped by the oil industry in Saudi Arabia, and in turn, the world oil market.

In 1944, CASOC changed its name to Arabian American Oil Company (ARAMCO). It continues exploration in the East region of Saudi Arabia and operates on what became known as the largest oil refinery in the world, Ras Tanura, in 1945.

In 1948, Standard Oil of New Jersey (later Exxon, now ExxonMobil) and Standard Oil Company of New York (Socony-Vacuum Oil, later Mobil, now ExxonMobil) joined SOCAL (now Chevron) and Texaco (now Chevron) as owners of ARAMCO.

In 1950, Trans-Arabian Pipe Line (TAPLINE) was established to connect the Eastern Province with Lebanon and the Mediterranean region, originally the TAPLINE was meant to reach Haifa, Palestine which was then under the

British mandate, but due to the establishment of the state of Israel, an alternative route was selected via Syria's Golan Heights and Lebanon to terminate in Sidon. This pipeline that is 1,700 kilometres long and 30 inches wide was, at the time, the world's largest oil pipeline system carrying 300,000-500,000 bbl/d, it was an important factor in international oil market trade, operated by the TAPLINE company, a joint venture between Standard Oil Company of New Jersey (now ExxonMobil), Standard Oil company of California (Chevron), the Texas company (TEXACO, now Chevron) and Socony-Vacuum oil company (ExxonMobil); it eventually became a fully-owned subsidiary by ARAMCO and continued operating until 2002 when it was terminated.

A tax break of 50% on oil profits 'Golden gimmick' was laid upon US oil companies in 1950, the deal was inaugurated by King Abdulaziz and ARAMCO to receive 50% of oil profits. This was inspired/influenced by Juan Pablo Perez Alfonzo²⁵ of Venezuela who used the same 50/50 tax break with Standard Oil Company of New Jersey and Royal Dutch Shell. Venezuela eventually led the establishment of OPEC to protect the rights of national oil companies.

3.5.2 Stage II: The Emergence of a Rentier State (1951-1973)

Different terms have been suggested as a way of theorizing oil-based economies in the literature: dutch disease (The Economist 1977), rentier state (Beblawi 1990), inherited prosperity (Porter 2008); all of which refer to the fact that nations whose economy is heavily based on God-given resources produce revenues *effortlessly*, this might create a trap and slow down efforts to pursue development via utilizing human capital and form an industrial and knowledge based economies.

²⁵ Juan Pablo Perez Alfonzo is the former Venezuelan Oil Minister and OPEC co-founder and a prominent diplomat, politician and lawyer. He is known for his 1970s famous quote: "Ten years from now, twenty years from now, you will see: oil will bring us ruin... Oil is the Devil's excrement."

The term Rentier State²⁶ (Beblawi 1990) was originally coined to describe Iran as a country that depends on rents from natural resources, therefore, economic development is said to be effortless but unsustainable as it depends on an exhaustible resource, oil.

In 1953, King Abdulaziz died and was succeeded by his eldest son King Saud, who remained in power for 11 years and was then abdicated in 1964 in favour of his brother King Faisal.

As more and more oil fields were discovered, oil trade continued and the oil industry started to flourish, which fuelled economic development in Saudi Arabia. In 1956, Ghawar and Safaniya Saudi oil fields were regarded as the world's largest onshore and offshore fields, respectively.

In 1961, the first liquefied petroleum gas (LPG) plant was processed at Ras Tanura and shipped to international energy markets.

Economic planning has started informally in the 1950s and was short-run in nature, however, King Faisal was the one who introduced it formally under his reign and established economic planning institutions and councils to conduct it periodically based on five-years period and covering all aspects of the economy (Looney and Frederiksen 1985).

Saudi Arabia was faced by inflation in 1956, after which foreign economic development planners and advisors were invited in 1960, which has resulted in the establishment of the Supreme Planning Board of Saudi Arabia, later the 'Ministry of Planning' (Daghistani 1979).

The first development plan by the Ministry of Economy and Planning (MEP) was introduced in 1970 (-1975) and was focused on maintaining high levels of

²⁶ Hazem Beblawi describes four characteristics for *rentier states*: (i) if rent situations predominate (ii) if the economy relies on a substantial external rent – and therefore does not require a strong domestic productive sector (iii) if only a small proportion of the working population is actually involved in the generation of the rent (iv) and, perhaps most importantly, which the state's government is the principal recipient of the external rent (Beblawi 1990, pp. 87-88).

oil production to maximize oil profits to support an expanding economy, employment, and a better standard of living (Looney and Frederiksen 1985). It has also included goals such as *“to raise the standard of living, promote general welfare, provide for national security and economic and social stability while retaining religious values”* (Daghistani 1979). The first period was regarded as a success since GDP figures have outgrew expectations.

3.5.3 Stage III: The Booming of Oil Wealth in a Petro Economy (1974-1985)

By 1973, Saudi Arabia has experienced rapid growth from oil wealth during the period 1974-1982, a period known as “the oil boom” where GDP per capita skyrocketed by 1,858% (The World Bank 2008).

The second development plan (1975-1980) has maintained plans to increase employment, raise standards of living, but also introduced an objective to reduce dependence on oil, diversify the economic base and develop human resources (Daghistani 1979, Looney and Frederiksen 1985). Challenges facing the Saudi economy during this stage include a vital need for public administration and organization, oil-dependent economy, increased inflation, little infrastructure, and inadequate manpower supply with low education level, and the conservative religious groups that often oppose modern changes that comes with economic development.

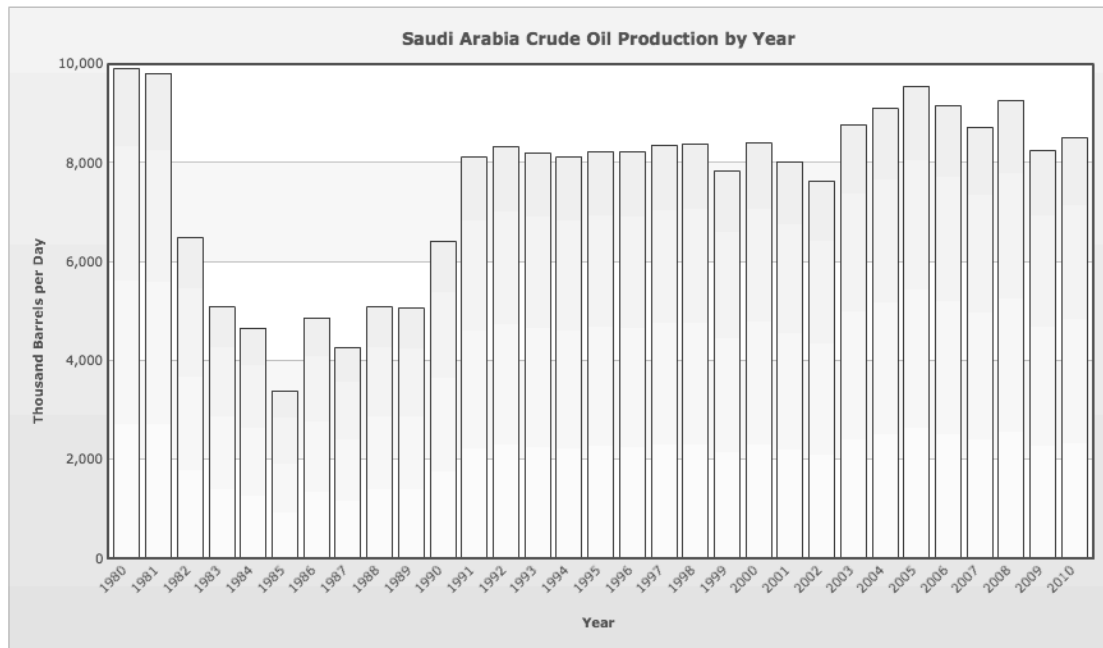


Figure 3-8 Saudi Arabia's Oil Production by Year, 1980-2010 (Source: US EIA 2011)

The figure shows oil production by year in Saudi Arabia between 1980-2010, in 1973, Saudi Arabia acquired 25% of oil profits in Aramco. Oil revenues have increased 25 times from 1970 to 1979 (Hertog 2009). Soaring oil prices due to 1973 Arab-Israel war put Saudi Arabia amongst the fastest-growing economies in the world. Because oil revenues boomed in 1974, likewise, construction of infrastructure and industrial city of the East Province has also risen. In 1976, Bechtel was contracted to build Jubail Industrial City and was completed successfully by the late 1980s, and by 1992 it was one of the most modern cities in Saudi Arabia.

Several important defining political events have occurred which have had a direct influence on Saudi Arabia and led to many restructuring – the Iranian revolution, the signing of Camp David Treaty, the second “oil embargo”. These have changed the arrangements in Saudi Arabia, more particularly, a wave of ‘nationalism’ was spreading in the region which has also led to restructuring in Saudi Arabia’s oil industry. Perhaps as a result, in 1980, Saudi Arabia gained 100% participation interest in Aramco. However, Saudi Arabia started acquiring some interests since 1973.

The second development plan included the following objectives: “*massive investments in physical infrastructure, the preservation of hydrocarbon resources and increases in exports of energy intensive industries, an improvement and expansion of the government, increased private sector participation, through diversification of the non-oil sector*” (Looney and Frederiksen 1985, p. 9).

Generally, the plans were met but were challenged primarily by inflation. The establishment of the petrochemical industry took place by 1976, Saudi Arabian Basic Industries Corporations (SABIC) was established to produce oil derived products: chemicals, polymers and fertilizers.

The third development plan (1980-1985) focused on objectives to diversify the economic base of the Kingdom still reliant on oil. Other objectives included: structural change of the economy, increasing participation in economic development, and economic and administrative efficiency (Looney and Frederiksen 1985).

3.5.4 Stage IV: Pursuing Economic Liberalisation (1986 – 2000)

A booming population in the eighties has slowed down economic development; GDP per capita has shrunk by 58%. However, by the nineties, economic development resumed recording a 20% growth (World Bank 2008). The oil boom of the 1970s and early 1980s has quadrupled the country's income and therefore has driven the government to invest in taking the country to a higher level to enable it to ‘compete globally’. By 1988, Saudi Aramco state-owned oil company was established, the previous name of ARAMCO was changed and it has now become 100% owned by the Saudi government.

The fourth development plan (1985 – 1990) was characterized by the shift in manpower (Looney 1990), it focused on “*streamlining the administration and reducing / eliminating unnecessary support and subsidy programmes*”. It had four themes to address the Kingdom's long-term challenges: (i) the operational efficiency of resources and facilities; (ii) the diversification of

production activities (such as manufacturing, agriculture and finance); (iii) the goal of reducing the number of foreign nationals working in the Kingdom by 500,000, especially unskilled labour; and finally and arguably most importantly, (iv) involving the private sector and creating a much more active role in industries that are financed and administered by the government (Looney and Frederiksen 1985).

Privatisation in Saudi Arabia started in this stage, perhaps the most successful of these is the privatization of the ICT sector, the telephone system is the first privatization of a government utility (Obaid 2000). Askari (1990) argues that a national output in Saudi Arabia, given its oil-based economy, is a unique concept and is different to non-oil-based economies (p. 13). Askari (1990) writes that the Saudi Industrial Development Fund (SIDF) granted US \$4.1 billion by 1984 to help finance 830 factories that were expected to provide more than 50% of funds required for economic diversification projects in Riyadh for the Kingdom to move away from hydrocarbon-related industries.

Wheat production in Saudi Arabia has driven the agriculture sector to export a growing production, starting from 130,000 tons in 1970s and growing to over 2 million tons in 1986, reporting fifteen-fold growth in 16 years (Askari 1990). However, this endeavour has harmed the sustainability of Saudi Arabia's water resources, of a mostly desert land (as discussed in chapter 2).

Privatisation and trade liberalisation has been actively pursued by other GCC countries at the time, at different scales, such as the deregulation and privatisation of water, energy, solid waste management sectors, and countries such as Qatar, Oman, Saudi Arabia and UAE have pursued economic liberalisation by opening-up to foreign direct investment (FDI) under the general agreement on trade in services (GATS) (AFED 2009, p. XVII).

Beginning in 2000, FDI was the new objective, and hence Saudi Arabia's government investment authority (SAGIA) was created to encourage investments and remove protectionist barriers, as well as open the Kingdom to globalization. Economic liberalisation and diversification included opening

the natural gas industry to foreign investment, privatising certain industries and working towards accession in WTO (UNFCCC 2005).

In summary, during this phase, privatization has emerged slowly, FDI materialised albeit slowly, however, bureaucratic reforms were still challenging, and capital market reforms took place successfully to a certain degree (Hertog cited in Paache 2007). This phase of nearly four decades could be described as the 'catching up' of Saudi Arabia through its economic liberalization via privatisation and opening up to globalization, the shift at this stage showed a clear new direction that Saudi Arabia was taking towards modernization.

3.5.5 Stage V: Financial Powerhouse and Plans for Reform (2000-2005)

Economic development has continued to flourish through the fifth stage with nearly doubling of the GDP, growing from SR 706,657 [£121,874] bn in 2000 to SR 1,152,600 [£198,784] bn in 2005 (IMF 2006). Economic growth during this stage has recorded an average annual growth rate of GDP of 3.4%, diversification has also continued with non-oil sector growth recording 3.9%.

Also, Saudi Arabia became then the largest US trade partner in the Middle East, in 2005, US-Saudi two-way trade accounted for 34 billion dollars (Yamani 2006). Moreover, The largest stock market in the GCC is in Saudi Arabia, with a market capitalization of \$237.1 bn at the end of 2004, with an average daily trading volume of \$1.93 bn it also is regarded as the most active of the GCC stock markets (Bley and Chin 2006).

The seventh development plan for 2000-2005 continued focusing on privatisation and economic diversification, and added a particular emphasis on human resource development of the Saudi workforce. The main focus of this phase has been on six areas: (i) human resource development of the national workforce for better job opportunities, (ii) privatisation policy to increase participation by citizens in ownership and productivity, (iii) improving government agencies administration and organizational efficiency, (iv) adjustments to global economic development, (v) technological advancement

and building a national science and technology base through private/public partnership, and (vi) boosting efficiency of available resources (MEP 2010).

3.5.6 Stage VI: Founding the Building Blocks for Technological Innovative Capacities (2005-2025)

The final stage which Saudi Arabia has embarked upon is what it aims shall be the founding of building blocks for technological innovative capacities. This stage will be further explored, building on from chapters leading to the case study on Saudi Arabia (chapter 6 and 7) and overall findings and discussion (chapter 8). It includes efforts that are pertinent to economic development with a focus on technological innovation capacity and carbon management technologies.

The Kingdom of Saudi Arabia plans to make major long-term investments in science, technology and innovation. The aim is to secure a leading international position, over a 20-years period, in science and technology and to build substantial new economic activity based on innovation and technological development.

Examples of initiatives include: The Saudi National Innovation Eco-system (KACST 2011), the national science, technology and innovation policy (Chapter 7), the latest MEP Eighth Development Five-Year Plan (2005-2009) shows a clear indication of aspirations to transform the economy into a Knowledge-Based Economy (More to be discussed in chapter 7).

Discussing economic development in oil states has always presented the challenge of economic diversification. In Saudi Arabia, as presented earlier, the challenge has always been acknowledged, this is also reflected in each of the five-year development plans since it started in 1970 and until the eighth development plan. It has included 'economic diversification' as an objective and more recently as on-going achievement.

More challenges that characterise the future of Saudi Arabia, as stated in the eighth development plan (MEP 2010), include: (i) high population growth, (ii) need to improve quality of life and standards of living through the Kingdom,

(iii) high unemployment estimated at 7% in 2004, (iv) unsustainable use of resources, particularly water, (v) activate WTO membership requirements, and (vi) national workforce human resources development.

3.5.7 Political System

The government of Saudi Arabia is an absolute monarchy with a Council of Ministers, the executive body is essentially the king who acts as the chief of state and head of government, the legislative body comprises of a Consultative Council (*Majilis Alshura*) and the judicial party compromises the Supreme Court, Supreme Judicial Council, Islamic Courts of First Instance and Appeals. There are no political parties and no democratically elected parliament. There are 13 provinces across the Kingdom, each headed by a prince from the royal family.

3.5.8 The Saudi Oil Policy

The literature on Saudi oil policy is rather limited. On the one hand, there is a view that oil policy in Saudi Arabia is characterized by “oil opacity” (Simmons 2005, Marcel 2006), with policies driven by ‘royal whim’ and an unstructured strategy. On the other hand, Obaid (2000) and Cordesman and Obaid (2005) argue that Saudi oil policy has followed a professional and structured approach based on the experience of a full-fledged team, at least since 1999 (Obaid 2000). There are a number of factors that shape oil policymaking, amongst which are: (1) oil prices, (2) oil geopolitics and (3) technology innovation in the energy sector (Al-Naimi 1997).

Al-Youssef (1998) explains a typical hierarchical approach to Saudi oil policymaking, where the king is placed at the top, with direct contact with the supreme petroleum council (which existed between 1973-1977). Today, there is a supreme economic council, which will be discussed later, overlooking the council of ministers, and the ministry of petroleum and mineral resources which overlooked Petromin (existed between 1962-1998), as well as overlooking Saudi Aramco, and the ministry communicates with OPEC and OAPEC.

Oil policy in Saudi Arabia followed an administrative structure, although sometimes the close relationship between the King and the Minister of petroleum and mineral resources has expedited the rather bureaucratic nature of decision-making in the oil industry, for example King Faisal and former oil minister Zaki Yamani, this however has changed when King Fahd acceded the throne (Al-Youssef 1998).

When it comes to Saudi oil decisions, Quandt (1981) explains that they are driven by two schools of thoughts, the first emphasizes economic factors to sustain expenditure, and the second major school of thoughts emphasizes political considerations.

Yizraeli (2000) explains the power of Saudi Arabia to influence oil prices through its oil policy, she gives an example of the somewhat active and even aggressive policy on the oil embargo that has impacted the global oil market.

To understand Saudi oil policy, it is important to first examine the institutional set-up that underlies oil policymaking. The main institutions that have shaped oil policy are: (1) The Supreme Council for Petroleum and Minerals Affairs, (2) The Ministry of Petroleum and Mineral Resources, and (3) Saudi Aramco (Obaid 2000).

Table 3-3 Saudi Oil Policymakers (Source: Obaid 2000, edited)

Institution	Individuals of Authority	Ad-hoc committees key actors
Supreme Council for Petroleum and Minerals Affairs	Minister of Foreign Affairs, Prince Saud	Minister of State, Dr. Mohammed Al Sheikh
The Ministry of Petroleum and Mineral resources	Minister of Finance and National Economy, Dr. Ibrahim Al Assaf	Minister of State, Dr. Musaed Al Ayban
Saudi Aramco	Minister of Industry and Electricity, Dr. Hashim Yamani	Deputy Minister of Oil, Prince Abdulaziz bin Salman
	Minister of Planning, Khaled Al Ghosaibi	Deputy Foreign Minister, Dr. Youssef Al Sadoun
	President of King Abdulaziz City for Science and Technology, Dr Saleh Al adhel	
	Former Deputy Minister of Finance and National Economy, Abdulaziz Al Rashid	
	Saudi Aramco President and CEO, Abdullah Jumah	

Table 3-3 above shows the institutions, individual and ad-hoc committee key actors that are involved in oil policymaking. This is according to Obaid (2000), and although the institutional set-up remains the same, some individuals' names have changed in the table.

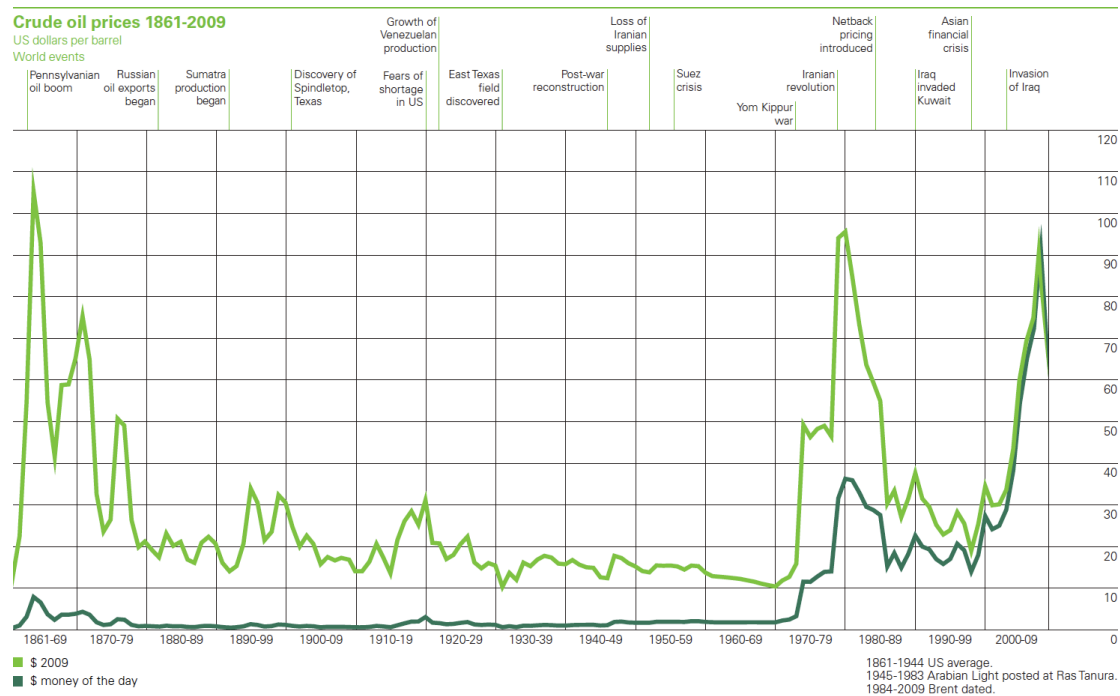


Figure 3-9 Crude Oil Prices for the Period 1861-2009 (Source: BP, 2010)

The figure illustrates crude oil prices for the period 1861-2009 showing two graphs, the upper graph (light green) shows the prices in US dollars of 2009, the lower graph (dark green) shows prices in their real value of the day (BP 2010).

The Kingdom has been keen on keeping its oil policy in line with a healthy world economy, King Abdullah (then Crown Prince) explains that in an interview with the Financial Times:

"Oil is a strategic commodity upon which the prosperity of the industrial as well as the developing countries depends. Our oil policy is a prudent one, seeking a balance between the interests of producers and consumers. It serves no purpose to speak about oil outside this framework." (FT 2004)

Saudi Arabia has kept mechanisms to optimize oil production and market share as well as oil price levels (Yizraeli 2000). Obaid (2000) explains that Saudi foreign policy is a subset of its oil policy, typically characterized by its relationship with exporters and importers. According to Obaid (2000), there are two options for Saudi Arabia's long-term oil policy, Option 1 - Price Maintenance, maintain reasonable prices but regulating supply, and Option 2

– Flood-the-market approach, by increasing supply to maximize returns. Oil policy is defined by the international political and economic environment, which is characterized by rapid changes.

Saudi Arabia's oil minister, Al-Naimi (1997), summarises Saudi oil policy and explains that it is based on five premises: (1) high oil and gas reserves, (2) daily oil production, (3) reserve (back-up) capacity, "on stream, very efficient and without delay," (4) stability of the world oil market, the environment and international economic health, and (5) acquiring and developing technology to advance its expertise.

The Saudi-US relations is a major influence of oil policy in the Kingdom, Lippman (2010, p. 73) explains that both countries have cooperated 'under the radar' in a joint economic commission (JECOR) whose purpose was "*to promote programs of industrialization, trade, manpower training, agriculture, and science and technology,*" he argues that such programmes helped in 'channelling money back' to the USA.

Since the discovery of oil in 1938 and until 1973, Saudi oil policy concerned 'extracting the best fiscal terms from the concessionaire companies' ruled by its major oil companies Exxon, Chevron, Mobil and Texaco (Al-Youssef 1998, Golub 1985). From 1973, Saudi Arabia has arguably taken a more active role (Al-Youssef 1998) and perhaps even aggressive (Yizraeli 2000). Long (1979) writes at a time when US oil imports from the Kingdom accounted for 20%, and the effect of Saudi oil policy would have a direct impact.

Saudi oil policy was detrimental in shaping the direction of the global oil market, a 1981 quote from OPEC by Yamani explains (Rostvik 1992, p.14):

"If we force [by raising prices] western countries to invest heavily in finding alternative sources of energy, they will. This will take them no more than seven to ten years and will result in their reduced dependence on oil as a source of energy to a point, which will jeopardize Saudi Arabia's interest. Saudi Arabia will then be unable to find markets to sell enough oil to meet its financial requirements."

Saudi Arabia prides itself as the energy provider to the world and it realizes such role is too valuable to squander. It therefore puts every effort to be perceived as a *reliable* energy provider, this was often emphasized in speeches addressed by Saudi official representing the oil industry. However, it also realises that it is a political tool to protect its vital interests. For example, the 1973 oil embargo decided by King Faisal exhibit the power of oil, however, even this decision has been announced after a number of warnings (according to Obaid 2000) and it is related to regional affairs, namely the continued Palestinian-Israeli conflict. Therefore, the Saudi oil policy could be perceived as “a security valve for the world economy” (Al Aqeel 2010) and is characterized by a delicate balance between its relationship between consumers and producers.

3.6 Sustainable Energy in Saudi Arabia

3.6.1 Environmental Policy in Saudi Arabia

Saudi Arabia regards Islamic teachings as a major source of governance, and considers the Holy Qur'an as its constitution. Islamic teachings are inclusive to many aspects of development and at various levels from personal to country-wise. Sustainability and the environment is a subject that is addressed in the Holy Qur'an. *Sustainable development*, which emerges as a framework to tackle environmental concerns (see next chapter), is seen at the essence of Islam (Bagader *et al.* 1994), which advocates ‘the middle way’ (alsiratt almostaqeem) and condemns the development that leads to the corruption of the environment. Environmental sustainability is a concept that is revisited in the Quran and Hadith, for example:

"But seek, through that which Allah has given you, the home of the Hereafter; and (yet), do not forget your share of the world. And do good as Allah has done good to you. And desire not corruption in the land. Indeed, Allah does not like corruptors. " [Quran 28:77]

"If the Hour is imminent and anyone of you has a palm shoot (to plant) in his hand and is able to plant it before the Hour strikes, then he should do so and he will be rewarded for that action." [Hadith]

"And there is no creature on (or within) the earth or a bird that flies with its wings except that they are nations (communities) like you." [Quran 6:38]

In this section, a brief summary is provided on the history of environmental policy in Saudi Arabia that is pertinent to the oil industry and the energy sector.

Article 32 of Saudi Arabia's Basic Law of Governance (issued by Royal Order No. A/9 on 1 March 1992) provides that: "The state shall endeavour to preserve, protect and improve the environment and prevent its pollution" (BOE 1992). The Article also provides law for protecting public health, conserve and develop natural resources, it also covers environmental planning as well as, raise public awareness and encourages collective responsibility and national voluntary efforts to preserve the environment (BOE 1992). The table below shows selective major environmental events and laws that are pertinent to the oil industry and the energy sector in Saudi Arabia.

Table 3-4 Selective major environmental events in Saudi Arabia (Source: Al-Gilani and Filor 1997, edited)

Legislation	Year
First commercial oil production	1938
Water resources conservation law (M/34 1400 H)	1980
Establishment of MEPA (7/M/8903) and EPCC	1981
Environmental Standards (01-1409)	1982
Obligation to Use the Best Available Technology to Reduce Pollutant Emissions and to Reclaim Quarries and Dispose Waste (CM/271 1404H)	1984
First State of the Environment report, SoE-84	1984
Conference on Environment and Development in Saudi Arabia	1990
Gulf War: Kuwait Oil Spill	1991
The National Report to UNCED—Rio	1992
Agenda 21: Saudi Arabia (CM/78 3/7/1415 H)	1995
Saudi Environmental Awareness Project	1995
First National Conference on Environmental Pollution and Health	1996

The Presidency of Meteorology and Environment (PME) was created to defy environmental degradation and protect natural resources. It is the central agency responsible for environmental protection and monitoring in Saudi Arabia. The general role of PME is to: (i) review and evaluate the condition of

the environment; (ii) conduct environmental studies; (iii) document and publish environmental information; (iv) prepare environment protection laws, standards and regulations; and (v) promote environmental awareness.

Moreover, MEPA's duties overlook entities such as ministries, departments and other government establishments to ensure that it must: (a) observe the environmental regulations, standards and criteria; and (b) adopt necessary procedures to co-ordinate and co-operate with each authority which is empowered to approve projects which may negatively impact on the environment.

A recently created nongovernment organization is the Saudi Environment Society (SENS), whose mission is to support governmental effort through advisory, research and educational and awareness campaigns through private/public collaboration as well as collaboration with civil societies in the Kingdom. The main values that SENS is based upon are borrowed from Saudi Arabia's Basic Law of Governance, these are: respect for the environment, responsibility to protect the environment, partnerships and collaboration on environmental project, quality and practicality of work process, continuous improvement and focus on results and output of such projects (SENS 2011).

Table 3-5 Major Multilateral Agreements Status in Saudi Arabia (Source: Selected from Raouf 2008)

<i>Multilateral Agreements</i>	<i>Year</i>	<i>Status</i>
Heritage Convention Concerning the Protection of the World Cultural and Natural Heritage	1978	Acceded
Basel Convention on the Transboundary Movements of Hazardous Wastes and their Disposal	1990	Ratified
CMS: Convention on the Conservation of Migratory Species of Wild Animals	1991	Acceded
Vienna Convention for the Protection of the Ozone Layer	1993	Acceded
United Nations Framework Convention on Climate Change (UNFCCC)	1994	Acceded
The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)	1996	Acceded
United Nations Convention on the Law of the Sea (UNCLOS)	1996	Ratified
United Nations Convention to Combat Desertification (CCD)	1997	Acceded
United Nations Convention on Biological Diversity Cartagena Protocol on Biosafety to the Convention on Biological Diversity (CBD)	2001	Acceded
Stockholm Convention on Persistent Organic Pollutants (POPs)	2002	Signed
Kyoto Protocol of Climate Change	2005	Acceded

The table shows the major multilateral agreements that Saudi Arabia has acceded, ratified or signed.

Civil society plays an important role in environmental protection by participation of the society in the overall governance of the country. Saudi Arabia is an absolute monarchy and citizens have no participation in policymaking, it also does not allow the establishment of civil society organisations, including environmental organizations. However, environmental activism could be considered to be at its infancy stage, for example, there are small start-up groups such as Al Nabta [literally, plant], Jeddah Recycle and other college projects that have materialised into active groups in the society.

3.6.2 Renewable Energy Potential:

Saudi Arabia sits across the world's highest direct sunlight belt, receiving as much as an average annual solar radiation of about 2,200 kWh/m² (Alawaji 2001). Moreover, being home to the world's "largest continuous sand desert" – *Al Rub' Al-Khali*, the Empty Quarter (OPEC 2010), also, Saudi Arabia receives enough daily solar radiation in its Empty Quarter Desert that could power two Earths (ESIA 2011).



Figure 3-10 Twelve Solar Radiation Monitoring Stations Across Saudi Arabia (Source: El Yousef 2010)

The figure shows twelve stations scattered across Saudi Arabia dedicated to monitor solar potential, these are (El Yousef 2010): 1) Solar Village; 2) Qassim; 3) Al-Hasa; 4) Wadi Al-Dawaser; 5) Sharurah; 6) Gizan; 7) Abha; 8) Jeddah; 9) Al-Madinah; 10) Tabouk; 11) Al-Jouf; 12) Al-Qaisumah. There are also five wind monitoring stations (El Yousef 2010).

3.6.3 Renewable Energy Exploitation

3.6.3.1 Solar Energy

Research on exploiting renewable sources of energy in Saudi Arabia dates back to 1960, with small-scale university projects in 1969 (Alawaji 2001), it however started officially in mid-1970s by the Saudi Arabian National Centre for Science and Technology (SANCST), now King Abdulaziz City of Science and Technology (KACST); two major international join-ventures were accomplished SOLARES as a collaboration with USA and HYSOLAR a collaboration with the Federal Republic of Germany.

SOLARES

In 1977, USA signed an agreement with SANCST to collaborate technically in the field of solar energy for the mutual benefit of the two countries at a full cost amounting to US \$50,000,000 [£31,542,250] (UNTS 1979). The village was completed in 1981, with 350 kW solar photovoltaic (PV) power system supplying 1-1.5 MWh/day to three villages, it was regarded the first in terms of size and complexity (El Yousef).

Solar Hydrogen Demonstration Plant (HYSOLAR)

The second project was a solar-powered hydrogen production plant as a collaboration with Germany in 1986 and was regarded as the world's first plant of this kind in terms of capacity. The objective was to acquire and transfer scientific knowledge for commercial production and use of solar hydrogen in Saudi Arabia at the size of 350 kW solar PV plant. Other solar energy application projects by KACST include using solar PV for tunnel lightening, desalination plant and solar dryers (Alawaji 2001).

KACST has recently (25/01/10) launched a major national project to use solar energy for water desalination and electricity at a very cheap rate of 30 halalas [£0.05] per kilowatt/hour. This has been achieved as a project between the ministries of finance, water and electricity and commerce and industry and the Saline Water Conversion Corporation (Arab News 2010).

3.7 Conclusion

In this chapter, an overview on the country case of Saudi Arabia has been provided. It started with a country profile followed by an explanation of the importance of Saudi Arabia in the world economy, then a brief on the Saudi energy sector and the stages of economic development, also, it provided an understanding of how oil policy is made in the Kingdom, and finally, a section on sustainable energy in Saudi Arabia, including environmental policy and renewable energy potential and renewable energy exploitation activities.

4 Conceptual and Theoretical Frameworks: Systems of Innovation and Sustainability Transitions

This chapter provides a background on the frameworks to be used and the methodology followed in this dissertation. The first part explains concepts and theories, these include: the national system of innovation (NSI) framework, sustainability transition theories, and reflexive governance for innovation policies. These are presented and articulated to help answer the questions that this dissertation aims to answer. The objective of this chapter is to present a workable framework to be applied to the case study of Saudi Arabia to help (1) articulate the Saudi NSI (2) define the different SI applying to the country case study and (3) construct transition sustainability-pathways.

Chapter Content:

- 4 Conceptual and Theoretical Frameworks:
 - 4.1 Sustainability
 - 4.1.1 Global sustainability
 - 4.1.2 Regime sustainability
 - 4.1.3 Niches Sustainability
 - 4.2 The System of Innovation Approach
 - 4.2.1 Technical change at the heart of economic development
 - 4.2.2 Technology
 - 4.2.3 National System of Innovation Approach:
 - 4.2.4 Comparing Indicators of Innovation Systems
 - 4.2.5 Processes for Developing Countries Innovation Systems:
 - 4.3 Transition Management and Reflexive Governance
 - 4.3.1 Multi Level Perspective
 - 4.3.2 Socio-technical transition paths
 - 4.3.3 Transition Management:
 - 4.3.4 Reflexive Governance
 - 4.4 Discussion
 - 4.5 Methodology

Introduction

The basic objective of this chapter is to provide a theoretical framework necessary to develop the arguments and attempt to answer the research questions of this dissertation, which aims to discuss (a) how to *materialise* the characteristics of a national system of innovation (NSI), (b) how transition paths to sustainability are constructed for an oil-based economy, and, (c) how innovation policy could *spur* energy technology innovation within an oil-based economy, and finally, (d) what form of governance is required to adopt innovation policies to spur carbon management technologies. All these concepts and theories have been extensively researched separately and intertwined, particularly in the past decades with the momentum of environmental sustainability emerging and then escalating. These frameworks are coupled with the subject matter of cleaner energy and environmental sustainability, and how these could be pursued at a country level, and how such *sustainability pathways* are constructed, especially considering different levels of analysis, departing from a country's *national system of innovation*.

Therefore, this chapter aims to summarise some main and other selective arguments in the literature of national system of innovation (NSI) and transition management (TM) to present a theoretical and an analytical framework to first understand and then examine and analyse the subjects under this study, namely, cleaner energy, the environment and sustainability for the case study of Saudi Arabia.

The chapter however does not intend to provide a survey of the whole body of literature, and is organised as follows: 4.1. Sustainability; 4.2. the system of innovation approach; 4.3. transition management and reflexive governance.

4.1 Sustainability

The roots of sustainability thinking go back as late as the 1700s when Malthus published his work on population growth; it however only emerged again strongly in the 1970s (Dalal-Clayton and Bass 2000). Environmental sustainability in particular goes back further in early history during the Golden Age of Muslims in Al-Andalus (711-1492) [now Spain]; Environmental treaties,

especially on pollution, were documented in Arabic written by al-Kindi, al-Razi, Ibn Al-Jazzar, al-Tamimi, al-Masihi, Avicenna, Ali ibn Ridwan, Abd-el-latif, and Ibn al-Nafis; The subjects covered included air pollution, water pollution, soil contamination, municipal solid waste mishandling, and environmental impact assessments of certain localities. Moreover, Cordoba in [then] al-Andalus is believed to have had the first waste containers and waste disposal facilities for litter collection (Gari 2002; Scott 1904; Arts 1980; Al-Hassani 2007).

Sustainable development is a framework that has emerged into the academic and policy circles, today, there is a ministry of sustainable development in the Nordic countries and a number of international institutions have widely used the framework (OECD, World Bank, UNIDO). It was introduced to the global arena as an overarching aim in the late eighties by the Norwegian Prime Minister Gro Brundtland; She chaired the first commission to study the fate of the global environment, which was created under the United Nations General Assembly, this was published in the Brundtland Report (WCED 1987). The message urged nations to live responsibly and that each generation must preserve Earth to the next with its vital resources intact. The definition of sustainable development that has become most-widely cited: *“Development that meets the needs of the present without compromising the ability of future generations to meet their own needs”* (WCED 1987, p. 43).

If sustainable development is the objective that sets the direction, *sustainability* is the process. It *“refers to a process and a standard—and not to an end state—each generation must take up the challenge anew, determining in what directions their development objectives lie, what constitutes the boundaries of the environmentally possible and the environmentally desirable, and what is their understanding of the requirements of social justice”* (Meadowcroft 1997, p. 37).

Sustainability science is proposed as a new type of science that is described as mode-2 science (Martens 2006) whose properties, comparing to mode-1 science, deals with academic and social (instead of only academic), trans- and interdisciplinary (instead of mono-disciplinary), participative (rather than

technocratic), uncertain and exploratory (rather than certain and predictive) (Kemp and Martens 2007). Sustainability science also explores the ‘coproduction of knowledge’ in a systemic perspective and emphasizes the coevolution nature of complex systems, through learning-by-doing and learning-by-using, sustainability science focuses on system innovation and transitions (Kemp and Martens 2007).

In technical terms, sustainability means “a path along which the *maximization of human well-being for today’s generations does not lead to declines in future well-being.*” (OECD 2001b, p. 6). The *levels of analysis* for understanding the concept of sustainability are important. It seems, indicators of sustainability, therefore, will differ if different levels of analysis are considered. Some key indicators are presented here, using the multi-level perspective (MLP) to explain the levels of analysis. The MLP considers three levels, namely the *macro*, *meso* and *micro* levels, each of these corresponds to landscape, [patchwork of] regimes, and niches [novelty], respectively. The framework will be discussed at length in the following section (4.3) in this chapter. Here, it provides a useful grouping to understand the indicators of sustainability at each level. Perhaps the timescale of each of these also correspond to the manner at which happenings occur. While at the micro level technological innovations occur fastest at a short-term timescale, at the meso level changes through regime shifts take longer at a medium-term timescale, and at the macro level paradigm shifts in the landscape occur much slower at a long-term scale.

Identifying ‘unsustainability forces,’ – a proposed term to simply describe the *lack* of sustainability direction or elements, therefore, it becomes important to identify these in order to pursue sustainability; this is to be measured at each level to assess progress on how it could be corrected to fit the framework at hand.

4.1.1 Global sustainability

Global sustainability is a suggestive term that could be used to explain a highest level of analysis at the macro level, with the three key pillars known as

'the three E's of sustainability', Economy, Environment and Social Equity, or sometimes called 'the three P's of sustainability', Planet, People and Profit. Fourth dimensions have been suggested, for example, "political" (UNESCO 2010) "institutional" (IAEA 2005); especially when pursued at a lower level of analysis.

The broad concept of sustainability, therefore, could be described as a 'guiding vision,' steering or *heuristics* that set the direction to tackle the challenges for development, and since such comprehensive approach cannot be undertaken at a global scale by a single body, it is important to further 'contextualize' it into a workable set of indicators to be practically pursued individually at a country-level.

Efforts to *contextualize* the concept of sustainability into workable framework are increasing, especially with much interest from policy circles in adopting the term in national plans and policies, for example: The Norwegian Sustainability Ministry (Brutland 1987), the German Federal Ministry of Economics (Gerken 1996), Sustainable America (PCSD 1996). One example of *measuring* sustainable development is to develop environmental indicators, such as resource accounting in Norway (Pearce and Warford 1993). An international initiative to define a set of Energy Indicators for Sustainable Development (EISD) and corresponding methodologies and guidelines (IAEA 2005), this has been accomplished by the International Atomic Energy Agency (IAEA) in cooperation with the United Nations Department of Economic and Social Affairs (UNDESA), the International Energy Agency (IEA), Eurostat and the European Environment Agency (EEA). Other efforts to translate sustainable development into workable strategies and indicators include for example a resource book edited by Dalal-Clayton et al. (2002) and WEA (2000).

Agenda 21 (UNCED 1992) from the Earth Summit urged governments to set their national strategies for sustainable development. Governments have increasingly taken the task to their agendas, for example, Norway was the first country to set a Ministry for Sustainable Development, today, there are many

countries with a Ministry for Sustainable Development, for example Sweden, Finland, Denmark, and Canada. International bodies (OECD, IAEA, UNEP) provided frameworks for encouraging countries to create their national strategies for sustainable development.

4.1.2 Regime sustainability

Regime sustainability is a suggestive term to explain the meso level of analysis of the term. More specifically, it could be used to apply sustainability on the [patches of] regime level. Voß et al. (2006) explain the principles of sustainability in seven criteria: 1) Human-ecological systems integrity; 2) Sufficiency and opportunity; 3) Equity; 4) Efficiency and throughput reduction; 5) Democracy and civility – political decision; 6) Precaution; and 7) Immediate and long-term integration. These are the sort of sustainability-criteria that are to be applied. The framework of NSI presented next, could be regarded as a sustainability tool that works on forming the infrastructure required to support and spur technological innovations.

Here, the *meso* level of understanding is where sustainable development is approached from a country-level and is defined by what that country sets as its priority. This is further explained through understanding its different dimensions to understand what is it that must be sustained, there are four dimensions to consider: economic, social, environmental, and institutional (IAEA, 2005).

Sustainability is applied to different patches of regimes, one example is developing a national set of energy indicators. IAEA (2005, pp. 11-15) developed this set of indicators based on the four dimensions of sustainability. There are 30 indicators in total that are classified into 19 sub-themes, 7 themes and 3 dimensions. These are as follows:

4.1.2.1 Social Dimension

- a. Equity – (i) *accessibility* (households without electricity), (ii) *affordability* (household income spent on electricity), (iii)

disparities (energy use by each income group household corresponding to fuel mix).

- b. Health – *safety* (accidents/fatalities per energy produced)

4.1.2.2 Economic Dimension

- c. Use and production pattern – (i) *overall use* (energy use per capita), (ii) *overall productivity* (energy use per unit of GDP), (iii) *supply efficiency* (efficiency of energy conversion and distribution), (iv) *production* (reserves-to-production ratio), (v) *end use* (energy intensities by industrial, agricultural, service/commercial, household and transport), (vi) *diversification of fuel mix* (fuel shares in energy and electricity, non-carbon energy share in energy and electricity, renewable energy share in energy and electricity), (vii) *prices* (end-use energy prices by fuel and by sector).
- d. Security – (i) *imports* (net energy import dependency), (ii) *strategic fuel stocks* (stocks of critical fuels per corresponding fuel consumption).

4.1.2.3 Environmental Dimension

- e. Atmosphere – (i) *climate change* (GHG emissions from energy production and use per capita and per unit of GDP), (ii) *air quality* (ambient concentrations of air pollutants in urban areas, air pollutant emissions from energy systems).
- f. Water – *water quality* (contaminant discharges in liquid effluents from energy systems including oil discharges)
- g. Land – (i) *soil quality* (soil area where acidification exceeds critical load), (ii) *forest* (rate of deforestation attributed to energy use), (iii) *solid waste generation and management* (ratio of solid waste generation units of energy produced, ratio of solid waste properly disposed of to total generated solid waste, ratio of solid

radioactive waste to units of energy produced, ratio of solid radioactive waste awaiting disposal to total generated solid radioactive waste).

These indicators need to be contextualised to each country's economic and energy profile (IAEA 2005). It is important to remember that these indicators are developed for 'sustainable energy' and can be used to measure progress in sustainability in that regime only, rather than the entire economy. In the following section (4.3.) looking at 'transition management,' other indicators are to be considered if sustainability is to be pursued at a broader perspective to include carbon management technologies and technological innovation in the energy sector. While it is difficult to measure sustainability across an entire economy, Kemp and Martens (2007) explain that because sustainable development is a subjective concept, it requires 'deliberate' forms of governance and assessment, this will be explored in the following section (4.3).

4.1.3 Niches Sustainability

At the micro level, sustainability is about sustaining technological innovations that occur in the short-term in strategic sectors in an economy. Developing a (diversified) portfolio of carbon management technologies would be as a way for 'niches sustainability' for the energy sector as well as coupling the portfolio with sustainability tools that will provide feedback for policy (reflexive governance). However, such technological innovations are only possible in the context of a 'national system of innovation' developed around these 'technological systems of innovation' for a country.

To manage sustainability, OECD (2001a, p. 120) explains:

A strong political commitment is crucial to achieve the policy integration needed to underpin sustainable development. ... Collective responsibility within government for implementation of decisions which support a sustainable development strategy needs to be clearly established, and include explicit procedures and an assessment of training needs. Coherence across government department and among different levels of government is vital.

Achieving sustainable development could be explained as attempting to arrive at utopia, it is indeed an 'ideal' state for the world and countries and is widely considered unachievable, however, the concept of sustainability came into the international agenda to entail balancing the sustainability of the three pillars so as to be taken at equal considerations, and as such it should 'set the direction' for *transitions* for sustainability and encourage its progress towards it, rather than achieving it.

Sustainability can be regarded as highly contextual, Kemp and Martens (2007) state that "sustainability is about locally suited options that are globally sustainable," however, there is likely to be a conflict between localism and globalism elements (Rosenau 2003, Kemp and Martens 2007), a fitting example is the sustainability of Saudi Arabia's oil-based economy and meeting challenges of global environmental sustainability.

Sustainability could carry different meanings to different countries and at different phases, at least in the short-medium term. For example, a deteriorating economic state characterized by institutional weaknesses in developing countries would have different priorities to a developed country whose economy is relatively flourishing and who is pressured to pursue environmental sustainability, Meadowcraft (1997) describes the importance of such balancing.

4.2 The System of Innovation Approach

In order to explain the framework of a national system of innovation (NSI), a brief discussion on technical change in the literature is first provided with a focus on understanding technology (and technology transfer) and how NSI has eventually emerged as a popular framework in academic and policy circles, and how it has been shaped over the course of the past two decades. Next, a comparison between indicators of innovation system is analysed, a focus on systems of innovation approach for developing economies will be highlighted.

4.2.1 Technical change at the heart of economic development

Chris Freeman brings to light the studies of innovation and dates its fundamental ideas back to Karl Marx in the 19th century and Joseph Schumpeter in the 20th century – both of which, he states, have “attempted to assign a more central role to technical innovation” but were regarded as too general (Freeman 1994, p. 463). Freeman explains how this was neglected from mainstream literature but reasserts that there has been a “general consensus that technical change is the most important source of dynamism in capitalist economies” (Freeman 1994, p. 463). The idea was also said to have originated by Rae: “Invention is the only power on earth, that can be said to create” (Rae 1834, p.15 in Ahmad 2007).

Therefore, technological innovation is placed at the heart of technical change in an economy; Schumpeter laid the foundation of innovation studies in economics to explain innovation, he introduced the *linear approach* to innovation which occurs over three stages, first, invention emerges as an idea manifest typically as a scientific invention, once it is scientifically feasible, for an invention then to become an innovation it must be economically feasible, an innovation then undergoes diffusion into the economy and society once it becomes socially acceptable. The so-called Schumpeterian innovation (as termed by Chris Freeman) is where the main concept has emerged. Schumpeter emphasised the role of the *entrepreneur* as an innovator driven by anticipated profit, he formed the ‘linear’ invention-innovation-diffusion approach, and a process of *creative destruction*, which explains how “new technologies disrupt and often replace older ones”.

This basic view of innovation (Schumpeter 1911) has then been adopted and developed, the re-interpretation of these Schumpeterian ideas is often referred to as Neo-Schumpeterian or evolutionary, for example: Freeman, Clark and Soete (1982), Freeman and Perez (1986), Giovanni Dosi (1988), Dosi et al. (1988). Freeman (1994), Nelson and Winter (1982), described as sharing the fundamental belief that “*capitalism is an economic system*

characterised above all by evolutionary turmoil associated with technical and organisational innovations.” (Freeman 1994, p. 464)

There is a wide literature that discusses and explains technical change albeit using different terms and from different perspectives: technical change, technology development, technological innovation, innovative capacity – all seem to refer to the same concept. For example the term ‘Technological Regimes’ by Nelson and Winter was explained as “a set of design configurations” which form the “basis of competition, research activities and agenda for development for firms and business units”; ‘Technological Paradigms’ is a similar term by Giovanni Dosi used to explain the economics of technical change, which somewhat extends the notion of ‘Scientific Paradigm’ by Kuhn, Dosi explains that such a paradigm has *exemplar* (artifacts) and *heuristics* (steering) characteristics which could be termed ‘Technological Trajectory’ resembling a *pathway*, Dosi also explains how technological innovation could be *continuous*, which results in a technology trajectory, and *discontinuities*, forming a new paradigm.

Hughes (1983) who produced the *Networks of Power*, examined the weaving together of institutions, interests, and national electrical infrastructure. Following on from Hughes, René Kemp introduced the socioeconomic dimension and uses the term ‘Technological Patterns’ and ‘Technological Transition’ to explain the “dynamic scale and learning effects of technical change” (Kemp and Soete 1992), he explains the *evolutionary* character in cost and performance improvements and emphasizes the socioeconomic environment and technology.

The term ‘Techno-economic Paradigm’ developed by Chris Freeman and Carlota Perez (1986) explains how radical technologies and accumulated experience (from other sectors) result in a new paradigm, “in every change, the new one has already emerged and developed” (C. Freeman), it conceptualises how technological (technical) change transfers the economy. Carlota has further provided original analyses of the different TEP that emerged over the decades and summarised it in her seminal work (2010).

Even though the term 'innovation' seems to be tied with ambiguity, for example, Nathan Rosenberg (1982) explains the process of invention, innovation and diffusion between firms, industries and countries - as a 'black box,' however, such attempts that were summarised above from the literature show how the understanding of technical change is being advanced and show how it follows a certain direction rather than haphazard (Kemp 1994).

Technology is described as 'tacit' or 'codified', in the technology (technical) innovation literature, however has been regarded as lacking structure and rigorous theory, amongst the various efforts to conceptualise it, Freeman describes five characteristics of Technical Innovation (2004): 1. Coupling (of changing technology, production and markets); 2. Creating (new products, processes, systems and industries); 3. Clustering (of groups of related innovations) Schumpeter 1939; 4. Comprehending (new skills, new technologies, new markets) and 4. Coping (with the technical and market uncertainty of innovation).

The understanding of innovation has changed and is covered in the vast literature that deals with (technological) innovation as a force for economic development. Traditionally, Schumpeter's linear approach to innovation has been explored at different levels of analysis depending upon the focus of the study. The national system of innovation framework, developed in the mid-80s is by itself an effort to materialize and perhaps theorize innovation at a country level. Here, the national system boundary emphasises economic development and often highlight the main forces that contribute in such development.

Innovation systems research has emerged over the last two decades, with contributions to the understanding of the innovation process, taking the Schumpeterian innovation concept of linear innovation towards the now systematic perspective to innovation. Departing from the idea that "Systems innovations are necessary to achieve sustainability" (Elzen *et al.* 2004), more and more interest is formed around the theoretical concept of NSI and how to further *contextualise* or *materialise* it in a country.

A growing number of concepts are appearing in the literature to describe the *innovativeness* or the ability of a country to create technological innovations that would contribute to its prosperity:

“Concepts such as ‘technological capability’ (Kim, 1980), ‘technological mastery’ (Dahlman and Westphal, 1982), ‘technological capacity’ (Bell, 1984), ‘innovative activity’ (Fagerberg, 1987), ‘innovation capability’ (Dahlman et al., 1987), ‘absorptive capacity’ (Cohen and Levinthal, 1990), ‘innovation system’ (Lundvall, 1992; Nelson, 1993; Edquist, 1997) and ‘innovative capacity’ (Furman et al., 2002) have been suggested as interpretative frameworks for analyses of this aspect of development” Fagerberg and Srholec (2009, p. 83)

For the sake of simplicity, in this dissertation the term ‘innovativeness’ will be used to describe the state of the system of innovation in its ability to spur, create, and manage innovations.

4.2.2 Technology

Scholars looking at innovation systems in developing countries have argued that for developing countries, ‘technology’ should be the focus point rather than ‘innovation’. This, they argue, is due to the weak institutional structure that characterizes developing economies. The technological capability of a nation remains crucial for its development, this also means that such technological capability contribute in defining the ‘innovative capacity’ of a nation (Furman and Hayes 2004).

Technology could be seen as the ‘building block’ of development, Nathan Rosenberg (1982) makes it clear:

“that both the determinants and the consequences of technological innovation raise issues that go far beyond the generally recognized domain of the economist and the economic historian.”

Moreover, NSI as defined in its original framework, Freeman (1978, p. 1) uses the term ‘technology’: “the network of institution in the public and private sectors whose activities and interactions, initiate, import, and diffuse new technologies”. Therefore, the NSI of a country should, in essence, focus on *initiating, importing and diffusing* new technologies to strengthen its ‘innovative capacity’ or innovativeness.

4.2.2.1 Technology transfer

Defined by OECD as “a broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst different stakeholders such as governments, private sector entities, financial institutions, non-governmental organizations (NGOs) and research/education institutions” (2001). The figure shows two definitions of technology transfer presented in Ueno (2009).

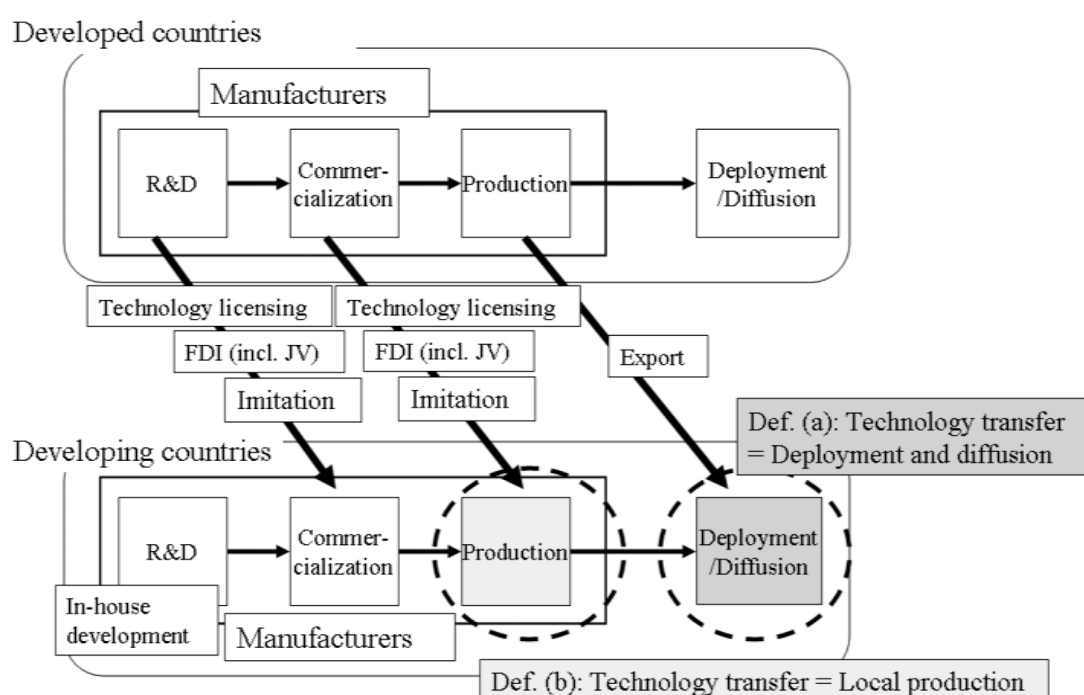


Figure 4-1 Technology Transfer Scheme (Source: Ueno 2009)

In developed countries, the source of innovation is developed, namely, in the manufacturing industry, R&D centres and production departments, upon commercialisation, technologies are then transferred through technology licensing, foreign direct investment (FDI), and joint ventures (JV), as well as the process of imitation, to developing countries.

4.2.2.2 NSIs as mechanisms for technology transfer

IPCC (2000) regards NSI as a mechanism for technology transfer that helps integrate the elements that constitute capacity building in a country, and provides access to information across the system as well as support the

creation of an innovation culture, the subsystems within an NSI and the quality of their interconnections form the basis for technology transfer.

The figure below shows a schematic diagram of the process of technology transfer, starting with (i) assessment and selection, (ii) agreement and implementation, (iii) evaluation and adaptation and (iv) repetition (Worell et al. 2001).

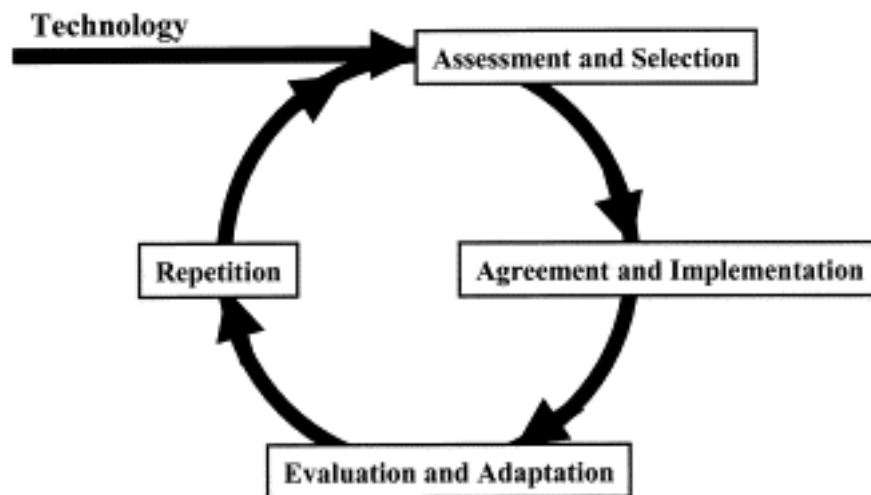


Figure 4-2 Technology Transfer Process (Source: Worrell et al 2001)

4.2.3 National System of Innovation Approach:

According to Chris Freeman, National System of Innovation (NSI) thinking goes back to Friderich List's "The National System of Political Economy", in his aspirations to advance Germany, he writes (List 1841, p. 3, *republished online 2006*)

"I felt that Germany must abolish her internal tariffs, and by the adoption of a common uniform commercial policy towards foreigners, strive to attain to the same degree of commercial and industrial development to which other nations have attained by means of their commercial policy."

Other scholars have described the principal concepts on the national innovation system emphasising different set of actors and functions:

<i>Reference</i>	<i>NSI Definition</i>	<i>Actors</i>	<i>Function</i>
Freeman (1987, 1995)	the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies	Network of institutions in the public and private sectors	initiate, import, modify and diffuse new technologies
Niosi et al. (1993)	the system of interacting private and public firms (either large or small), universities and government agencies, aiming at the production of science and technology within national borders. Interaction among these units may be technical, commercial, legal, social and financial in as much as the goal of the interaction is the development, protection, financing or regulation of new science and technology.	Private and public firms (large or small), universities, government agencies and their interaction	Production of science and technology within national borders
Lundvall (1985, 1992, 1998)	the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge and are either located within or rooted inside the borders of a nation state.	elements and relationships	interact in the production, diffusion and use of new, and economically useful, knowledge
Nelson (1993)	a set of institutions whose interactions determine the innovative performance of national firms.	Institutions	Interactions determine the innovative performance of national firms
Patel and Pavitt (1994)	the national institutions, their incentive structures and their competencies, that determine the rate and direction of technological learning (or the volume and composition of change generating activities) in a country.	National institutions	Determine the rate and direction of technological learning in a country.
Metcalfe (1995)	a set of distinct institutions which jointly and individually contributes to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies.	distinct interconnected institutions	Contributes to the development and diffusion of new technologies, provides the framework within which governments form and implement policies to influence the innovation process, create, store and transfer the knowledge, skills and artefacts which define new technologies.
Edquist (2004: 182)	All important economic, social, political, organizational, institutional, and other factors that influence the development, diffusion, and use of innovations	economic, social, political, organizational, institutional, and other factors	influence the development, diffusion, and use of innovations

Table 4-1 Definitions of NSI (Source: compiled by Author)

From the table above which provided selective definitions of principle definitions for the NSI, the institutions could range to include different sets that ultimately constitute the NSI: Freeman (1987) starts with a narrow definition of network institutions from public and private sectors, Niosi et al. (1993) even emphasise that these private and public firms could be large or small, and he also explicitly adds universities and government agencies, Lundvall (1985, 1992, 1998) on the other hand keeps it relatively broader and referred to these as 'elements and relationships' that make up the NSI, likewise, Nelson (1993) refers to them broadly as simply 'institutions', however, Pavitt and Patel (1994) specifically regard them as 'national' institutions, indicating that these are to be within national borders, to the contrary, Metcalfe (1995) believes they must be distinct 'international' institutions, located outside national borders. Edquist (2004) regards them as factors, be it economic, social, political, organizational, institutional and/or others.

In terms of NSI functions, these also range to include different functions (emphasis added): Freeman (1987, 1995) defined the function of an NSI as to 'initiate, import, modify and diffuse *new* technologies', he clearly emphasises the originality of the outcome 'new technologies' but also keeps it general, as he does not indicate where such technologies are developed, for example Niosi et al. (1993) indicate that the function is 'the production of science and technology *within* national borders'. Lundvall (1985, 1992, 1998) explain that the NSI function is to 'interact in the production, diffusion and use of *new, and economically useful*, knowledge,' which broadens the originality bit to include anything that is useful to the economy, he also emphasise the nature of the function to be in the form of 'knowledge'.

Nelson (1993) in his description of the NSI function: 'Interactions determine the innovative performance of national firms,' he highlights the importance of 'interactions' of the institutions, which will ultimately rule out the *innovative performance* of individual national firms. Similarly, Patel and Pavitt (1994)

believe the NSI ‘determine the rate and direction of *technological learning* in a country’.

Metcalf (1995) perhaps provide a holistic approach for the functions of NSI, like the other [combined] he also believes that NSI ‘contributes to the development and diffusion of *new* technologies, provides the framework within which governments form and implement *policies* to influence the innovation process, create, store and transfer the *knowledge*, skills and artefacts which define new technologies’

On the other hand, Edquist (2004) describes a more specific definition for the function of NSI in that it ‘influence the development, diffusion, and use of *innovations*’ where he places the attention on *attaining* innovations.

The figure below provides one of the earliest schematic diagrams that brings together the elements and functions of an NSI for a particular country (OECD 1999). The diagram shows how the ‘national innovative capacity’ is determined by a number of factors and actors, starting from the heart of the economy: firm’s capabilities and networks, science system, supporting institutions and other research bodies – together constitute ‘knowledge generation, diffusion and use’. This is embedded within broader networks: global innovation networks, clusters of industries and regional innovation systems as well as the national innovation system. The diagram also provides external influences that interact with these sets of networks: macroeconomic and regulatory context, communication infrastructures, factor market conditions, education and training system, and product market conditions. All of these factors and actors combined define the ‘country performance’ translated into growth, jobs and competitiveness. This perhaps provides a simple summary of where NSI fits, what are the constituents within and outside it, and how it should ultimately aim to drive a country’s performance.

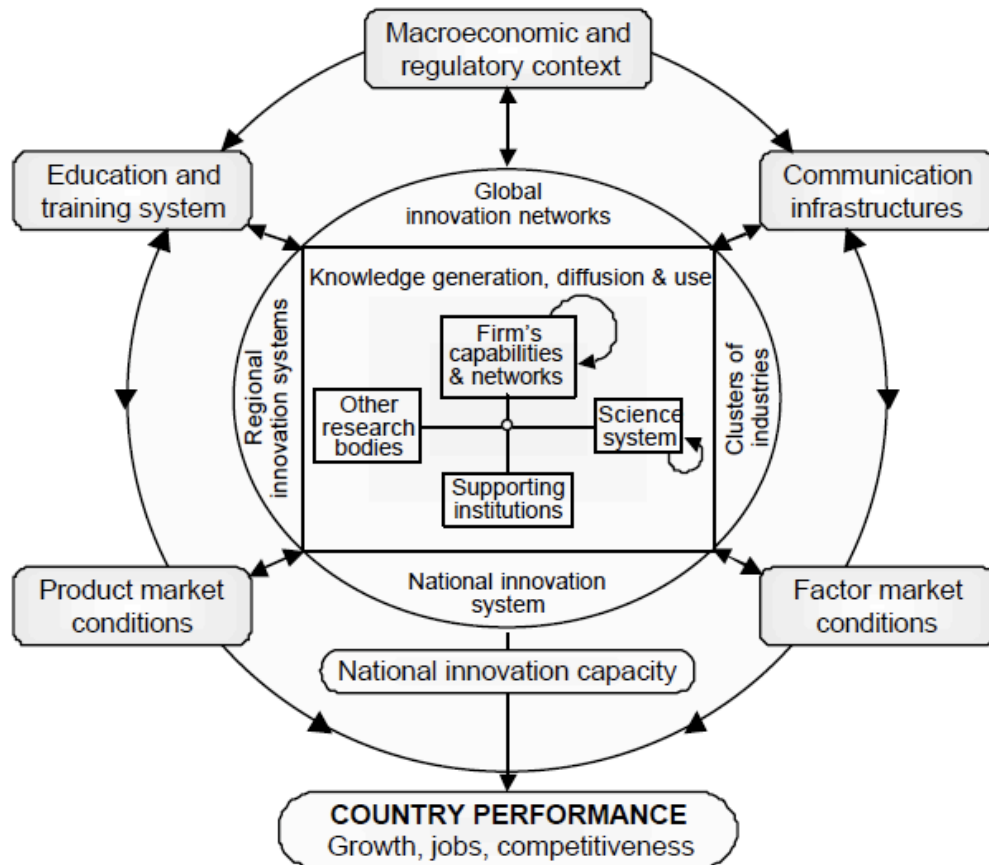


Figure 4-3 Managing a NSI (Source: OECD 1999)

Therefore, the NSI is greatly dependent on the position of the country and whether it has a developed, developing or less developed economy. A recently published handbook on innovation system and economic development (Lundvall *et al.* 2009) presents the current state of the art for research that links both domains of developing economics and innovation studies. The proposed definition is as follows (pg. 6):

“The national innovation system is an open, evolving and complex system that encompasses relationships within and between organizations, institutions and socio-economic structures which determine the rate and direction of innovation and competence-building emanating from processes of science-based and experience-based learning”.

Compared to earlier definitions that were described from the literature above, this definition (Lundvall *et al.* 2009) provides a customised view for countries that have developing economies with weaker institutions and infrastructure, particularly, the science-base. These NSIs are described as ‘open’ systems

that continuously ‘evolve’ and are ‘complex’ in nature, whose elements include organizations, institutions and socio-economic structures as well as their relationships between and within them. The function of such NSI is to ‘determine the rate and direction of *innovation* and *competence building*’ via processes that accentuate *science*-based and *experience*-based learning. Whereas mainstream literature on NSI, emphasised ‘innovation’ building.

The interactions between elements are described in the table below by Schoser to differentiate between formal/informal and narrow/broad elements: Narrow elements are those focused on science and technology, whereas broad elements include those that support innovation and general institutions that influence the innovation process. Formal elements are structured institutions, organizations and networks, whereas informal ones are those that are embedded in the society and institutions and do not follow formal processes.

Table 4-2 Interaction between formal and informal element of the innovation system
(Source: adapted from Schoser (1999) cited in Lundvall *et al.* 2009, p. 11)

	Narrow	Broad
Formal	(1) Science and Technology organizations, institutions and formal networks	(2) organizations supporting innovation in general, institutions & formal networks
Informal	(3) S&T informal institutions and informal networks	(4) informal institutions influencing innovation and informal networks (like cultural and historical values)

Carlota Perez summarises NSI succinctly: “The key point here is that individual technologies are not introduced in isolation. They enter into a changing context that strongly influences their potential and is already shaped by previous innovations in the system” (Perez 2010, pp. 188). She also emphasises the historic component in materialising an NSI. Therefore, the materialisation of NSI for a country requires an understanding of the past economic development of the country: “*That past history is an indispensable source of information to anyone interested in characterizing technologies*” Rosenberg (1982). This was also seen in almost all NSI case studies.

4.2.4 Comparing Indicators of Innovation Systems

Starting with the original framework, Freeman identifies the broadest system boundary that could eventually fit all indicators, by referring to a network of institutions. Different institutions and elements could be used for different levels of focus. Other system of innovation researchers took the NSI idea further to study it at different scales, such as the sectoral innovation systems (SIS) (Breschi and Malerba 1997; Malerba 2004), technological innovation systems (TISs) (Carlsson and Stankiewicz 1991) and regional innovation systems (RISs) (Cooke 1996).

In the sectoral system domain, Malerba (2002) identifies the main building blocks as: (i) knowledge base and learning processes; (ii) basic technologies, inputs and demand, with key links and dynamic complementarities; (iii) type and structure of interactions among firms and non-firms organizations; (iv) institutions; (v) processes of generation of variety and of selection (pp. 251). Because innovation systems ultimately pursue innovation-building, whether in a sector, a country or a region, therefore, building blocks are foundational and can often be common in every system of innovation. For example, the learning character as well as knowledge-building could be identified as a building-block for every system of innovation, similarly, technologies and the structure of interactions across networks and institutions are of equal importance in all systems.

Schmoch et al. (2006) identify six principles that characterise technological performance reporting: First, there are four groups that are studied to identify technological performance of a country these are: education and human capital, knowledge generation (R&D in private and public sectors), implementation of knowledge (patents, innovations, firm start-up), and market success and diffusion (productivity, production, employment, and foreign trade); second, there are different indicators depending on the sector, field and technology, and technology-intensive sectors have more weight; third, indicators analyse current trends as well as long-term ones that look through the history of indicators; fourth, indicators benchmarking are used for

reporting; and finally the fifth, indicators are used to identify factors of NSI performance, such as the interaction between and within industry and science, financing innovation, legal framework and policy support system (Schmoch et al. 2006, p. 4).

These building blocks and other indicators of functions of NSI [discussed later] will help provide a benchmark for reporting countries performance in terms of their innovative capacities. Preceding NSI indicators, reporting technological performances of countries goes back to 1985 and was focused on industrial innovation activities (Schmoch et al. 2006). Particularly, reporting includes that which is conducted by international organisations that develop ranking for countries and are often published in periodic reports, for example: European Commission, US Science and Engineering Indicators Report, among others.

For developing countries, specifically, Fagerberg and Srholec (2009) carried out a study on 75 developing countries, choosing indicators over 2000-2004 that are pertinent to the national system of innovation framework, these make up the 'social capabilities' of a nation that are necessary for technological catch-up to occur - these include: education system, financial system, business regulation, social capital, political system and openness.

Table 4-3 Indicators for Social Capability for a System of Innovation (Source: Summarized from Fagerberg and Srholec 2009)

Indicator	Dimensions	Weight	% of total variance
Technological capability	Scientific articles	0.96	
	PCT applications	0.83	
	R&D	0.86	
	Doctoral enrolment	0.74	
	S&E enrolment	0.62	
	Professionals	0.77	
	Trademarks	0.62	
	ISO 9000	0.76	
	Computer	0.93	
	Internet	0.93	
	Phones	0.92	
			67.0
Education system	Literacy	0.78	
	Primary teacher/pupil	0.75	
	Secondary enrolment	0.88	
	Tertiary enrolment	0.88	
			67.7
Financial system	Domestic credit to private sector	0.86	
	Stock market capitalization	0.78	
	Interest rate spread	-0.67	
	Bank non-performing loans	-0.52	
			51.2
Business regulation	Time to start a business	-0.52	
	Time to close a business	-0.49	
	Protection of	0.91	

	intellectual property		
	Law and order	0.75	
	Corruption	0.94	
			56.0
Social capital	Trust in other people	0.45	
	Civic engagement	0.80	
	Tolerance to homosexuality	0.91	
	Equal access to jobs for immigrants	0.79	
	Equal access to jobs for women	0.77	
			57.5
Political system	Index of democracy and autocracy	0.94	
	Civil liberties	0.93	
	Political rights	0.96	
	Executive index of political competitiveness	0.70	
	Legislative index of political competitiveness	0.73	
	Political constraint	0.76	
			71.0
Openness	Imports of consumption goods	0.56	
	Imports of final capital goods	0.85	
	Imports of intermediates thereof	0.70	
	FDI inward stock	0.73	
	Royalty and license payments	0.59	
			48.2

From the Handbook of innovation systems and developing countries, Fagerberg and Srholec (2009 – shown in Table 4-2) published a study on 75 developing countries [including Saudi Arabia], the majority of which are low-medium income, to determine their 'social capabilities' for technological catch-up. The indicators that were used include: **1. Education System**, (i) Literacy: the degree of literacy of the adult population, (ii) Primary teacher/pupil: the teacher-pupil ratio in primary education, (iii) Secondary enrolment: gross enrolments in secondary programme, (iv) Tertiary enrolment: gross enrolments in tertiary programme; **2. Financial system** – the degree of development and efficiency of financial institutions in a country, (i) Domestic credit to private sector, (ii) Stock market capitalization, (iii) Interest rate spread, (iv) Bank non-performing loans; **3. Business regulation** – innovation-friendliness of governance and bureaucracy, (i) Time to start a business, (ii) Time to close a business, (iii) Protection of intellectual property, (iv) Law and order, (v) Corruption; **4. Social capital** – the measure of the openness of society to people with different characteristics (origin, gender, sexual orientation, etc), (i) Trust in other people – the degree of trust among the citizens of a nation, (ii) Civic engagement – the willingness to participate in civic activities (such as signing a petition), (iii) Tolerance to homosexuality, (iv) Equal access to jobs for immigrants, (v) Equal access to jobs for women; **5. Political system**, (i) Index of democracy and autocracy, (ii) Civil liberties, (iii) Political rights, (iv) Executive index of political competitiveness, (v) Legislative index of political competitiveness; **6. Openness**, (i) Imports of consumption goods, (ii) Imports of final capital goods, (iii) Imports of intermediates thereof, (iv) FDI inward stock, (v) Royalty and licence payments.

In their study, GDP per capita has been plotted against different capabilities. For *technological capability* countries included: scientific articles, PCT applications, R&D, doctoral enrolment, S&R enrolment, professionals, trademarks, ISO 9000, computers, internet, and phones. Fagerberg and

Srholec (2008) explain the importance of including more than only (UPSTO) patents per capita as an indicator for innovation system:

“The problem with measuring innovation capability solely by patents is that patents are given to (globally novel) inventions. Minor innovations/adaptations, which arguably make up the bulk of innovative activity world-wide, will not be counted following this approach since such innovations are not patentable” (p. 1422).

The six indicators are used for identifying a country's ‘innovation system,’ these factors determine a country's innovative capacity. Regardless to which sector a country wishes to focus on and seeks to spur innovation in, the determinants of the ‘innovative capacity’ in a country will intersect to cover some or all of these determinants. The new approach to innovation suggests *interconnectedness*, and that is what the literature is leading towards: a workable framework that will enable the measurement of the determinants of innovation in a country by identifying and then measuring the constituents of the system of innovation (SI).

Fagerberg and Srholec (2009) use the term ‘social capability,’ coined by Ohkawa and Rosoovsky (1974), to assess a country's SI and explain that factors such as education, governance and honesty, and trust – should be included in the assessment of an SI: *“These socio-economic and political factors influencing innovation constitute the innovation system in which firms operate”* (Fagerberg and Srholec 2009, p. 84)

Moreover, efforts to ‘operationalise’ (Hekkert & Negro 2008) the systems innovation approach has been multiplying in the literature over the past decade. They provide useful benchmarks to measure performance of SI under TIS studies, which they refer to as ‘system functions’, that reflect key activities of a SI. These are shown below in Table 4-4 and include seven functions: (F1) *Entrepreneurial Activities*, (F2) *Knowledge Development*, (F3) *Knowledge Diffusion*, (F4) *Guidance of the Search*, (F5) *Market Formation*, (F6) *Resource Mobilisation*, (F7) *Support from Advocacy Coalitions* or *Creation of Legitimacy* (Hekkert et al. 2007; Negro 2007; Hekkert & Negro 2008). Each function has been given indicators that are adapted from Alpen et al (2009).

Table 4-4 Functions of a Technological System of Innovation (Source: Adapted from Hekkert et al. 2007 and Alpen et al. 2009: 46)

Function	Description
F1 Entrepreneurial activity	At the core of any innovation system are the entrepreneurs. These risk takers perform the innovative (pre-)commercial experiments, seeing and exploiting business opportunities. Indicators: number and degree of variety in entrepreneurial experiments, number of different types of applications, breadth of technologies used, the number of new entrants.
F2 Knowledge development	Technology R&D are prerequisites for innovations, creating variety in technological options and breakthrough technologies. Indicators: number and degree of variety in R&D projects, type of knowledge (scientific, applied, patents) that is created and by whom, competitive edge of the knowledge base, (mis)match between the supply of technical knowledge by universities and demand by industry.
F3 Knowledge diffusion	This is important in a strict R&D setting, but especially in a heterogeneous context where R&D meets government and market. Indicators: the amount and type of collaboration within and between actors of the innovation system, the kind of knowledge that is shared within existing partnerships, the amount, type and weight of official gatherings organized (conferences / platforms), and the configuration of actor-networks.
F4 Guidance of the search	This function represents the selection process that is necessary to facilitate a convergence in technology development, involving policy targets and expectations about technological options. Indicators: the amount and type of visions and expectations about technology, the belief in growth potential, the clarity about the demands of leading users.
F5 Market creation	This function comprehends formation of new (niche) market by creating temporary competitive advantage through favourable tax regimes, consumption quotas, or other public policy activities. Indicators: the domestic and export potential of markets, demand of the technology, institutional stimuli for market formation, uncertainties faced by potential project developers.
F6 Resource mobilisation	Financial and human resources are necessary inputs for all innovative activities, and can be enacted through, e.g. investments by venture capitalists or through governmental support. Indicators: availability of human capital (through education, entrepreneurship or management), availability of financial capital (seed and venture capital, government funds for RD&D), availability of complementary assets (complementary products, services, network infrastructure), level of satisfaction with the amount of resources.
F7 Creation of legitimacy	The introduction of new technologies often leads to resistance from established actors, or society. Advocacy coalitions can counteract this inertia and lobby for compliance with legislation/institutions. Indicators: public opinion towards the technology and how is the technology depicted in the media, the main arguments of actors pro or against the deployment of the technology, legitimacy to make investments in the technology, activity of lobby groups active in the innovation system (size and strength).

The table above provides a detailed understanding of what each function constitutes and what indicators to be used to measure each function. The set of functions developed by Hekkert et al. (2007) and complemented by Alpen et al. (2009) indeed help operationalise a SI, these functions are said to 'reinforce each other' and therefore occur simultaneously (Suurs and Hekkert 2009).

4.2.4.1 Interactions between indicators of the system of innovation:

System functions vary in importance and order, some are also prerequisites to others, for example, Hekkert & Negro (2008, p. 592) explain how some functions carry 'extraordinary importance' than others:

"A rise in entrepreneurial activities (F1) is observed when the system functions such as guidance of the search (F4) and/or market formation (F5) are well fulfilled. In several cases the positive guidance (F4) leads to an increase in entrepreneurial activities (F1) but a breakthrough does not occur, until a market is formed (F5) that provides entrepreneurs and investors with a long term, stable perspective."

Such prioritising of functions would guide policy and help establish prerequisites to spurring technological innovation in the energy sector. They (Hekkert & Negro 2008) also explain, based on reviewing a number of case studies on sustainable energy technologies, how positive interactions with system functions yield a technological breakthrough of emerging technologies, similarly, negative interactions may hinder the innovation system and revoke technological developments.

4.2.5 Processes for Developing Countries Innovation Systems:

Other processes of innovation system include factors that are particularly relevant for developing countries, as opposed to developed countries. Here, a special focus is given to processes of SI that are pertinent to developing countries.

4.2.5.1 Foreign Direct Investment

Marin and Arza (2009) explain the importance of FDI in SI for developing countries, they describe the *international involvement* of the multinational corporations in facilitating *knowledge flows* in a given national innovation

system through “*assuring not only access to a given piece of technology or knowledge but also involvement in international processes of knowledge creation and diffusion*” (p. 280). They put together a number of mechanisms that facilitate such international involvement, such as: (i) the movement of highly skilled staff from subsidiaries to domestic firms; (ii) demonstration effects involving the domestic firms’ observation and imitation of the superior technology in subsidiaries; (iii) purposeful transfers of knowledge from subsidiaries to local firms; (iv) competition effects (p. 287).

4.2.5.2 Indigenous firms

Barnard *et al.* (2009) explain that the role of *national champion firms* is a form of government intervention in developing countries. Such national champion firms are “firms that receive considerable state support with the expectation that they will contribute to a sector that is deemed strategic by government” (Barnard *et al.* 2009, p. 241). They argue that because the national champion firm is embedded in both the national and global context (innovation systems) they may be capable of influencing national development more generally. Though they emphasize that such *leading* role of national champion firms is also ‘limited’ because 1). It is unlikely for a leading firm to partner with a weak local firm when it can fulfil its needs elsewhere in the world, and 2). It is likely to follow MNC trends of using the local NSI for less knowledge-intensive needs only. Hence, it cannot be assumed that leading national champion firms will contribute to national development. It is possible that firms could ‘co-evolve’ with their home country, some important contributions is the advancing of scientific, technological and managerial expertise which could be seen as *real* contribution to *innovation* in their home country (Barnard *et al.* 2009).

4.2.5.3 Education Systems

Education systems in developing countries are also distinctly different to those of developed countries and according to Brundenius *et al.* (2009) the main challenges facing developing countries in their education system, include: 1). Lack of finance: trend to privatize higher education in developing countries; 2).

Lack of resources: pressures to strengthen university-industry linkages; 3). Brain drain and the international mobility of students; and 4). Lack of demand for the highly educated. As one of the building blocks, efforts must be taken to reform and improve education systems, especially in developing countries, as these produce the human capital that is required to eventually support and produce innovation across the economy.

4.2.5.4 Innovation Policies

Tilman Altenburg (2009) argues that the growing body of literature, which deals with innovation in developing countries, fails to recognize some important *peculiarities* of developing countries. Focusing on developing countries with low- to lower-middle income group, Altenburg argues that these countries are especially characterized to have *institutional weaknesses*, particularly from the perspective of *technological* and *innovative* capabilities. The author then suggests some key elements to be considered in innovation policymaking for developing countries; these are summarised below (Altenburg 2009, pp. 50-52):

- *Innovation policy should focus on inclusive innovations and their diffusion*
- *The focus of policies should shift from selective micro or meso level interventions to improving the functioning of basic market institutions*
- *The role of non-governmental agents as policy implementers and drivers of change should be encouraged*
- *Governments should always be held accountable for policy outcomes*

These important factors that must be addressed in policymaking reiterate the interconnectedness aspect of innovation between actors and factors, especially between private and public institutions. However, a particular importance is given to the role of the government, which in its capacity as the highest policymaker in developing countries, drives innovation processes in SI. This view is also shared by Pavitt and Patel (1999, p. 110):

“The technological competitiveness of firms inevitably depends on national systems of innovation, and national systems of innovation inevitably depend on government policy. The level of business-funded R&D is influenced by national policies (e.g., competition, macroeconomics), and also by the behaviour of national institutions (e.g., agencies funding basic research, banks and stock markets, systems of corporate governance)”

Measuring technological and innovative capacity for developing countries is a continuous challenge, Fagerberg and Srholec (2009) explain that “For a catching-up country, the appropriate level of technological capability tends to be a moving target”. It is because the ‘innovative capacity’ (Furman and Hayes 2004) is explained as a measure of the number of patents. Fagerberg and Srholec argue that it is *too limited* because they refer to ‘inventions rather than innovations’ and that patents do not measure the innovations/adaptations which “arguably make up the bulk of innovative activity worldwide” (p. 85). Similarly, ‘technological capability’ encompass more than quantitative inventions, it is explained as “the ability to make effective use of technological knowledge in efforts to assimilate, use, adapt and change existing technologies (Kim 1997, p. 4).

4.3 Transition Management and Reflexive Governance

After understanding sustainability (4.1) and the system of innovation approach (4.2), in this final section (4.3), an examination of transition management and reflexive governance is explored. It starts with an analysis of the multi-level perspective framework (4.3.1), followed by a discussion on socio-technical transition paths (4.3.2), this prepares the reader to the final sub-sections (4.3.3) transition management, and finally (4.3.4) reflexive governance. A conclusion (4.4) recaps the frameworks and theories that have been explored to be applied in the dissertation.

Literature on transition has started with the “S-curve” basic pattern, this old perception of transition which follows a ‘predevelopment, take off, acceleration and stabilisation’ pattern is said to be a unilinear and static view (Rotmans 2003). Now, more than one pattern is believed to be possible for a transition (Geels and Schot 2007; Berkhout et al. 2004). Transition management is a form of reflexive governance (Kemp and Loorbach 2006), it is a term developed in the literature especially to assist in tackling environmental problems for a shift towards sustainability (Rotmans et al 2001; Kemp and Loorbach 2006; Kemp et al. 2006; Loorbach 2007).

4.3.1 Multi Level Perspective

To understand systems innovations and technological regime shifts (Kempton et al. 1998), the Multi-level Perspective (MLP) has been developed (Rip and Kemp 1998; Geels 2000, 2002, 2004; Geels and Schot 2007). This has been described as an ‘institutionalist analysis of technical change’ that focuses on the three levels of analysis, micro, meso and macro, and their ‘co-evolution’ (Berkhout 2001) or as described by Kemp and Rotmans (2001): niches, regimes and socio-technical landscapes respectively.

MLP is a useful framework that offers an in-depth analysis into the different levels involved in a transition: “*The MLP proposes that transitions, which are defined as regime shifts, come about through interacting processes within and between these levels*” (Geels 2010).

Figure 4-4 represents the MLP framework as a nested hierarchy, three levels are considered, the first from the bottom is the *micro level* which constitute niches or novelties, these are technological innovations that are born in the science and technology domains at this level, they later diffuse into the higher level the *meso level* which constitute patchwork of regimes, these are the different sectors in an economy, finally the top level is the *macro level* which constitute the landscape, this includes changes that take place at a global level and which influence changes in the other two levels.

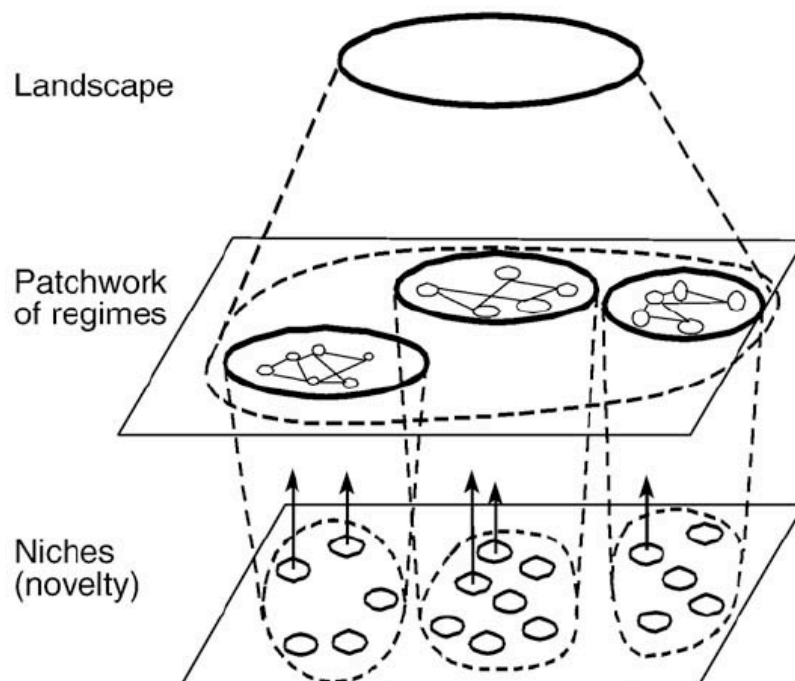


Figure 4-4 Multi-level Perspective as nested hierarchy (Source: Geels 2002)

The transition of the [patchwork of] regimes is a complex process that is determined by the degree to which these regimes are *locked-in* (Unruh 2000), and it is also determined by the nature of the *path dependency* (Arthur 1989), and how [technological] *momentum* (Hughes 1983) could spur innovations and speed up transitions to create *systems innovations* (Geels 2002). Hence, these factors determine the rate at which 'systems innovations,' occur and how they bring change to existing socio-technical regimes, and create transition paths towards sustainability (Geels 2002).

Rip & Kemp (1998) argue that in order to deliberately enforce technical change, an understanding of how technology is shaped by social, economic and political forces alike is vital (p. 238). This is best described in the ‘unpacking’ of the levels of analysis manifested in the MLP approach (Rip & Kemp 1998, p. 391):

“Since technologies initially grow best in niches, protected spaces for further evolution without the full force of selection being felt, policymakers can actively create such niches. As the technology becomes established, steps can be taken to reduce the protection afforded by the niche. Positive feedback through interactive learning and institutional adaptation occurs and, by creating a little bit of irreversibility in the right direction, the transition process is pushed forward. Transition paths are created in the attempt to traverse them”

Therefore, understanding how technological innovations are developed in each stage will help manage them. Starting at the niches level, protected spaces help spur technological innovations [in the science and technology domains]. For example, through funding research, and creating R&D and applied R&D activities, as well as encouraging experiments in labs, this will help in nurturing innovation in such spaces. Once technologies are developed, policymakers can help with the overall transition process by creating policies that will help adopt technological innovations. For example, by providing platforms for investment, technological innovations could be further developed and diffused into patchwork of regimes in the society and the economy. Meanwhile, institutional learning takes place across the economy and provides an infrastructure to support these technological innovations and helps maintain *sustainable* pathways for innovation.

The objective is to identify ways on “how to identify and realize transition paths from the present situation to a more desirable one” (Rip & Kemp 1998, p.371). These transition paths are constructed based on technologies and technology systems that eventually shape human relations and societies (p. 328), creating socio-technical transitions, which they argue could be created ‘deliberately’ rather than on their own, this is vital for creating solutions to climate change challenges.

The MLP approach is criticised as “unable to encompass the full variety of transitions” (Kamp et al. 2010). To answer these critics, Geels and Schot (2007) have created a typology of socio-technical transition: reorientation of trajectories, endogenous renewal, emergent transformation, and purposive transition.

4.3.2 Socio-technical transition paths

Another way of explaining transition is the socio-technical transition path developed by Geels (2002), which builds on the MLP framework. It breaks the different levels explored in MLP and identify factors which affect and assist a transition process. Starting at the micro level, different factors determine the emerging of technological innovation, termed ‘niche innovations,’ actors at this stage include networks that support the creation of innovation and the ‘co-construction’ of novelties using visions and expectations as well as interactions across networks.

Socio-technical regime constitute five dimensions (i) markets, user preferences, (ii) science, (iii) culture, (iv) technology, (v) policy, and (vi) industry (Geels and Schot 2007), these dimensions work simultaneously to assist in the transition process, other processes that may be embedded at this level includes technological regimes, regime shifts, strategic niche management, systems innovation, and transition management (Berkhout et al 2003).

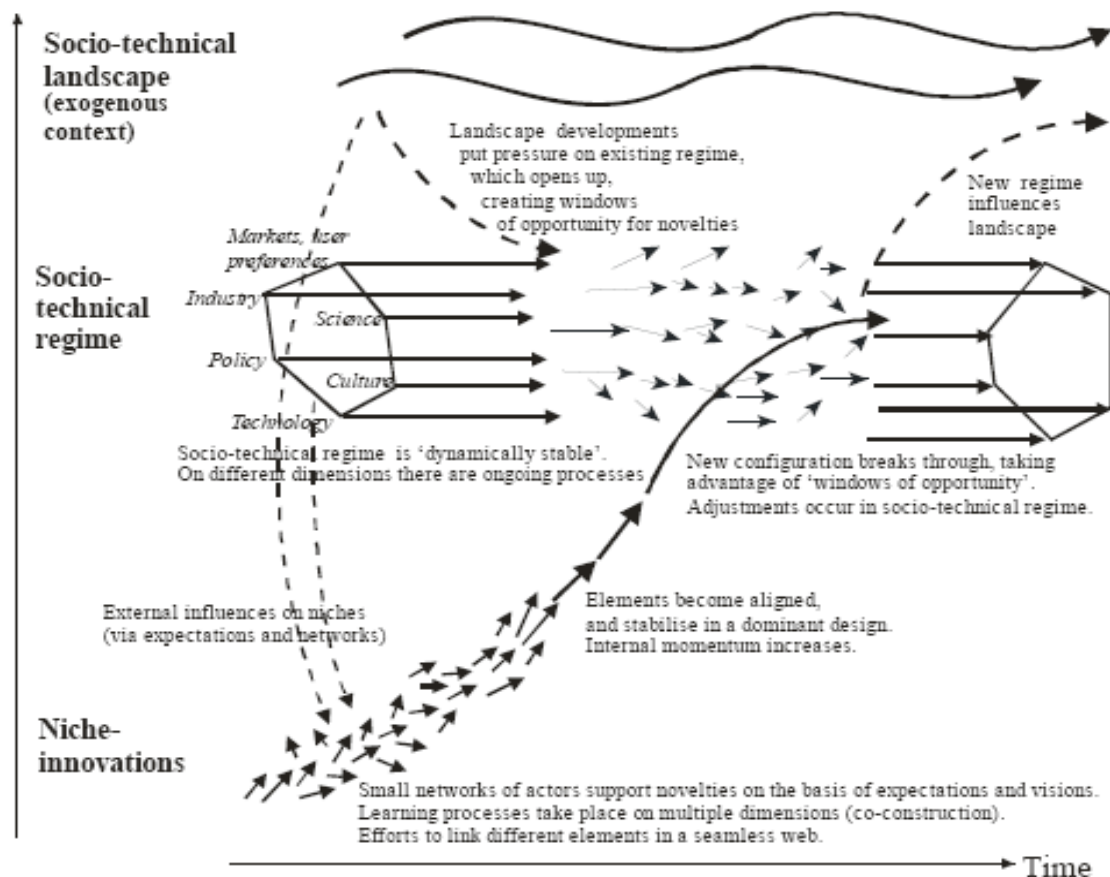


Figure 4-5 S-curve based socio-technical transition pathway (Geels and Schot 2007)

A socio-technical regime at the meso level is a dynamic process which allows new configurations from the niche-innovations micro level, such spaces are considered ‘windows of opportunity’ where elements from the micro level align – these are technological innovations that win out and emerge to become embedded in the regime level. Such ‘new configurations’ help shape the existing regime via ‘system innovation’ that encompass changes in the five dimensions – markets, industry, policy, technology, culture and science – towards a new socio-technical regime.

The socio-technical landscape at the macro level, or called the ‘exogenous’ context, is characterised by overarching landscape developments that ultimately shape the regime as well as the niches by exerting pressure on old regimes and opening ways for newer niches/regimes. Similarly, the new developed regime is shaped by co-evolutionary processes taking place across multiple levels that contribute in shaping the new [socio-technical] landscape.

The understanding of transition processes and the interactions across levels and domains is explored in the literature. Shove *et al.* (1998) explain that “change involves the co-evolution of interlocking systems,” such transformational change involves ‘major and complex technological and structural changes,’ that covers a range of sectors, including energy and the society. A similar undertaking is by Cowan (1984) who explored similar issues by studying the history of domestic gadgets and domestic labour in the household. Also, Bijker (1992) studied the fluorescent light case to explore technological diffusion. Berkhout *et al.* (2003) explain technological regimes, regime shifts, strategic niche management, systems innovation, and transition management as key processes for socio-technical regime. They explain niche-based model of regime transformation for transition management as ‘desirable technological configurations’ or also referred to as ‘societal configurations’ (Rip and Kemp 1998), social relations “link, use and make sense of” technological artefact.

Therefore, socio-technical changes use systems innovation as a mechanism for socio-technical re-arrangements. Processes of change involve a “co-evolutionary and socio-technical patterns in system innovations (outside-in) and actor-related patterns (inside-out)” (Berkhout *et al.* 2003).

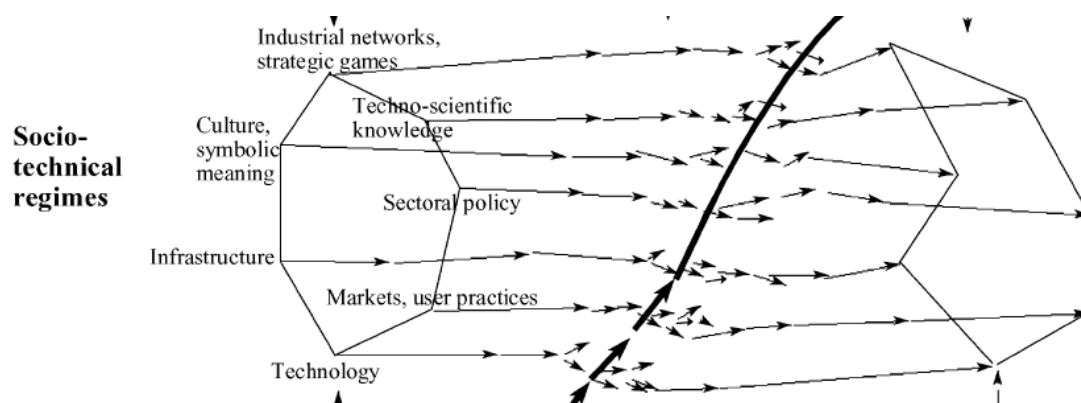


Figure 4-6 Socio-technical Regimes (Geels 2004)

Geels (2004) schematically represents and explains system innovations in socio-technical regimes, necessary for assisting in transitions towards sustainability in the figures above. There are seven dimensions that define the

boundaries of socio-technical regimes, these are: industrial networks and strategic games, techno-scientific knowledge, sectoral policy, markets and user practices, technology, infrastructure, and culture and symbolic meaning (Geels 2004). As represented, the transition process is managed by exploiting the seven dimensions of the regime, these are also shaped by pressures exerted from both the micro and macro levels. Kemp (1994) explains how technology that result in radical change is a gradual and slow process, which results in *new technological regimes*, which creates early market, knowledge, support and expectations.

The transition from one socio-technical system to another results in *system innovation* (Geels et al. 2004). Systems innovation is “defined as large-scale transformations in the way societal functions are fulfilled” (Geels 2004), Geels explains that such system innovation is a change in three aspects: 1. Technological substitution, which includes: (i) emergence of new technologies, (ii) diffusion of new technologies, and (iii) replacement of old by new technology, 2. Coevolution, for examples, changes not only to technology but also to elements such as user practices, regulation, industrial networks, infrastructure, and cultural meaning. 3. Emergence of new functionalities, which changes existing rules in clusters: technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks, and supply networks. Such changes are transformational in nature and cover a multitude of factors and actors: “the semi-coherent set of rules carried by different social groups” Geels (2004). Examples of societal functions are transport, communication, housing, feeding, energy supply and use (Geels *et al.* 2004, p. 3).

Therefore, socio-technical transition is achieved at the level of *societal functions*. It is because the society is at the heart of change: “Technology plays an important role in fulfilling societal functions, but its functioning depends upon its relationship to other elements” (Geels *et al.* 2004, p. 3). These simultaneous processes that are necessary to happen independently and interlinked has been explored in the literature, for example, the co-

evolution between industries, the government and universities termed “triple helix” dynamics (Etzkowitz and Leydesdorff 2000), and how firms, public authorities and universities work simultaneously in innovation systems or innovation communities have also been explored (Breschi and Malerba 1997; Malerba, 2002; Lynn *et al.* 1996). These also relate to research that studied and identified typology of innovation (Abernathy and Clark 1985).

4.3.3 Transition Management:

As presented in the first chapters, the rising momentum for the environment and the increasing concern for tackling climate change create a pressure on the oil-based modern world to pursue a transition away from fossil fuels. Unruh (2000, 2002, 2006) argues that the world system of energy is trapped in what he termed as ‘carbon lock-in,’ (2000) which:

“Arises through a combination of systematic forces that perpetuate fossil fuel-based infrastructures in spite of their known environmental externalities and the apparent existence of cost-neutral, or even cost-effective, remedies.” (p. 817)

Because existing systems are characterised by “stability, inertia, and lock-in” (Rennings *et al.* 2004), to pursue a more sustainable future, societies are challenged by the need to ‘lock out’ from carbon lock-in and prepare for a transition towards sustainability. The terms innovation, environmental innovation, sustainable innovation, innovation system, system innovation (Rennings *et al.* 2004) have been emerging in the heart of discussions when exploring ways to explain pursuing a transition towards sustainability and managing that transition. Voß *et al.* (2006) define transition management as a “forward-looking, adapting, multi-actor governance aimed at long-term transformation processes that offer sustainability benefits” (p. 103). This suggests that a transition pursues a futuristic state (sustainability), with some elements of prediction as well as an understanding of the current state (lock-in). It also suggests that transition must be characterised with ‘adaptivity’ to deal with the challenges and achieve change, it also works with different actors, agents and institutions across an economy that aims for a transformation towards sustainability.

As a result, transition management (TM) theorists such as Kemp, Rotmans and Loorbach developed some characteristics for TM thinking by breaking it down into a set of strategies, these also include embedded key concepts such as: knowledge integration, with a focus on learning such as ‘learning-by-doing’ and ‘learning-by-learning;’ in addition, an anticipation of long-term ‘systemic effects’ with an orientation towards ‘system innovation’; and an adaptation to change and developing strategies and institutions as well as ‘iterative participatory goal formulation’ and ‘interaction strategy development’ (Voß et al. 2006, Kemp and Rotmans 2004)

The main characteristics of TM thinking are summarised as follows (Rotmans et al. 2001; Rotmans 2002; Kemp and Rotmans 2004; Loorbach 2007; Rotmans & Loorbach 2010):

1. Social transformation that is multidisciplinary in nature
2. Long-term process of at least 25 years, and long-term thinking with a framework for short-term policy, such as ‘back-casting’ the setting of short-term and longer-term goals based on long-term sustainability visions and short-term possibilities, and ‘forecasting’ to reconcile uncertainties and predict future trends.
3. Multi-level large-scale developments including different scale levels, macro, meso and micro levels
4. Multi-domain including, technological, economic, ecological, socio-cultural and institutional developments
5. Multiphase which considers different system states
6. Simultaneous interactions which influence and strengthen each other, and involves interactions between developments at different scale levels
7. Encourage transitions through the creation of [socio-technical] niches and trying to change the strategic orientation of regime actors.
8. Consider the international aspects of change processes that inspire solutions to meet challenges

9. Initiate set of specific tasks for the government, “to stimulate, mediate, engage in brokering services, create the right conditions, enforce its laws and engage in steering.”

These characteristics help maintain a dynamic role for TM and also help identify ‘unsustainability’ elements that are rooted within social structures that involve a multitudes of actors, scales and requires a long-term perspective (Rotmans 2005).

4.3.3.1 The Dutch Transition Policies for Energy:

Kemp and Martens (2007) present an example of how transition paths construction takes place, they explain that there are different routes to be investigated, these are exemplified in diagram 4-7 below as transition paths A. “Gasification”, B. “Pyrolysis”, and C. “Biofuels”. Using transition pathways, decisions are made in an *interactive* as well as an *iterative* way, there are technology choices that are made at the decentralized level, support is temporary, and each option has to proof its worth in order to emerge. A transition path is defined as a “consistent set of actions, fulfilled preconditions and learning experiences that lead to fulfilment of the ambition formulated” (Kemp and Loorbach 2006).

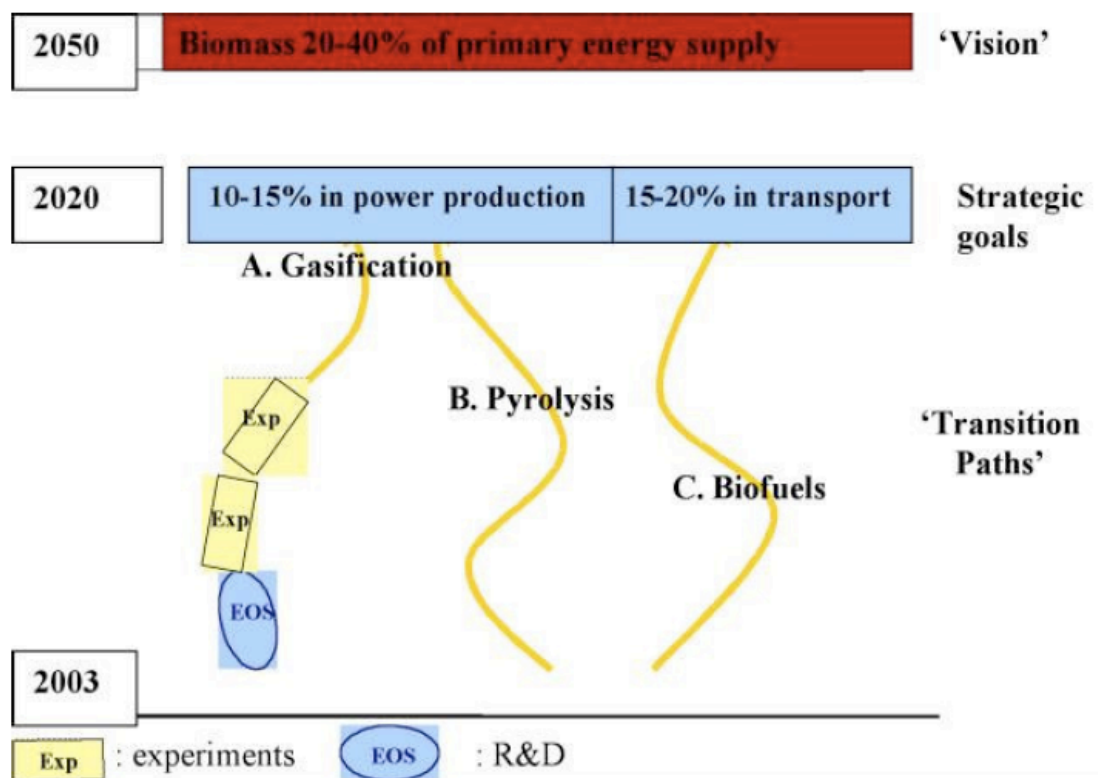


Figure 4-7 The Dutch vision for biomass (Ministry of Economic Affairs in NL 2003) cited in Kemp and Loorbach (2006)

Vision is the long-term objective and needs short-term objectives to form transition paths. Innovation pathways are not new in the literature, they have been explored in different domains as has been summarised by Karnoe (2001), these are referred to using different terms as follows, for example in economics: regimes (Nelson & Winter 1977), lock-in (Arthur 1989), homeostasis (Sahal 1985) and trajectories (Dosi 1982); in history, contingency (Mokyr 1992), momentum (Hughes 1983), path-dependence (David 1985), path creation (Karnoe 2001); in philosophy/politics: autonomy (Winner 1977), closure (Feenberg 1991), entrapment (Walker 2001), alignment (Geels 2002); in social studies: shaping (Bijker 1985), co-construction (Misa 2003), expectations (Brown 2003), imaginaries (Jasanoff 2005).

Transition pathways are innovation-oriented and can be described as the co-evolution in governance and socio-technical change, for “regime” changes, policy actions could be (i) immediate contribution [content goal], for example,

reduction in GHG emissions, and (ii) overall transition process [process goal] (Loorbach et al 2007).

Rotmans et al (2001) explain how transition management is emerging as an important tool in public policy, for example, the Netherlands's transition phase shows how development exist in different domains: "*a set of connected changes, which reinforce each other but take place in several different areas, such as technology, the economy, institutions, behaviour, culture, ecology and belief system*" (p. 2). Therefore, they emphasise *social change* and the co-evolutionary nature of such a transition phase: "multiple casualty and co-evolution caused by independent development" (p. 2).

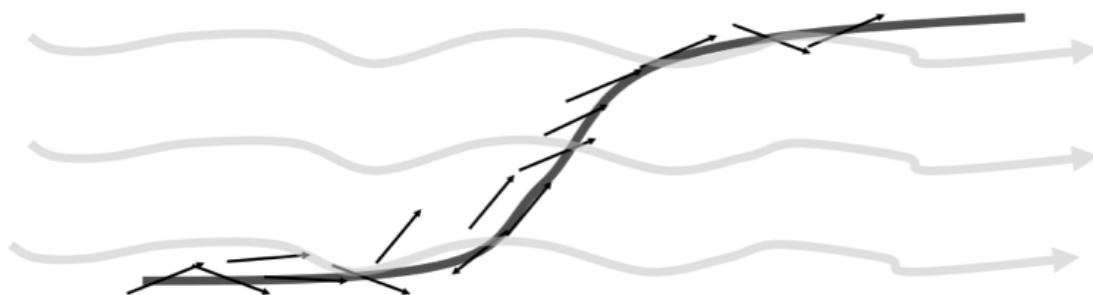


Figure 4-8 Transition Management (Source: Rotmans *et al.*, 2001)

Transition management in the above diagram is based on the classic S-curve, the difference is that the management of transition requires an understanding of where such a curve is embedded across other transition currents (represented in grey in the diagram), it also helps create policy decisions (perhaps exemplified in black short arrows) that help shape the bigger transition curve; Long-term developments are shown in stocks, and short-term developments in flows (Rotmans et al. 2000, 2001; Kemp and Loorbach 2006).

Long-term system effects for transition management are achieved through different methods, including: "*scenario-analyses and trend-analyses, back-casting and forecasting exercises and identification (and selection) of innovations*" (Kemp and Loorbach 2006).

Kemp and Rotmans (2004) offer a model for managing transitions to sustainability, this model was developed and used for the 4th National Environmental Policy Plan of the Netherlands (NEPP4) (VROM 2002 in Kemp and Rotmans 2004). The framework, which is presented in the diagram below, promises to integrate long-term sustainability views with shorter-term objectives to inform policy and manage transition, this *bi-focal* view is argued to meet existing societal goals as well as long-term sustainability visions (Kemp and Rotmans 2004, p. 143):

“The reliance on markets helps to safeguard user benefits and promotes efficiency, whereas the use of targets informed by long-term visions of sustainability helps to orient socio-technical dynamics to sustainability goals”.

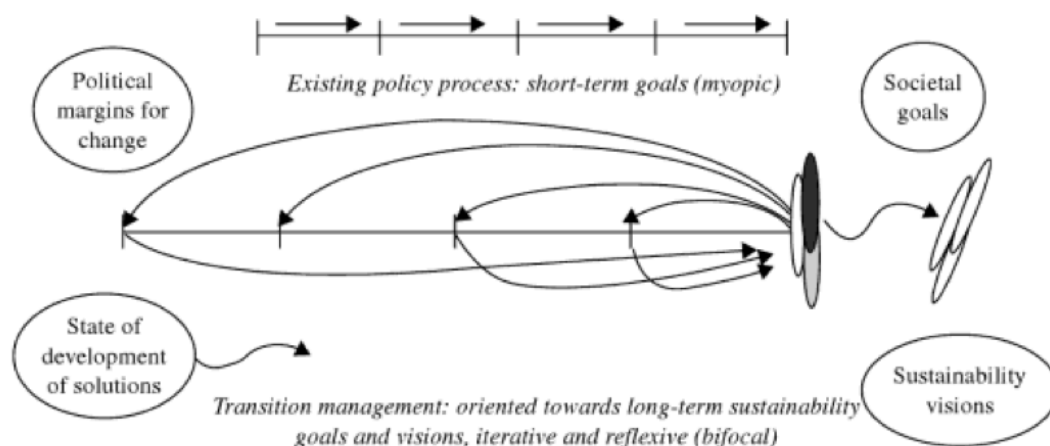


Figure 4-9 Transition Management bifocal diagram (Source: Kemp and Loorbach 2006, p. 110)

To have a sum-up on what transition management constitute: “Mathematically transition management = current policies + long-term vision + vertical and horizontal coordination of policies + portfolio-management + process management... is bottom-up and top-down, using strategic experiments and control policies” (Kemp and Loorbach 2006).

Using sustainability as a vision for policymaking has been assigned a positive role in the literature (Loorbach et al. 2007), Smith et al (2005) identify five functions that visions offer for policymaking: (1) *mapping a possibility space*, visions help identify areas that are possible options as means and platforms to pursue a particular vision, (2) *a heuristic*, that will guide problem-solving, (3)

a stable frame for target-setting, a vision that is well-defined will help create shorter-term benchmarks to measure performance, (4) *a metaphor for building actor-networks*, a vision would help in defining the actors to be involved in reaching that vision and more importantly create a unifying objective for these actors, (5) *a narrative for focusing capital and other resources*, similarly, once a vision is defined and objectives for the short-term, it will be easier to focus the available resources of time, money, human capital, and other resources to reach the short-term objective that will help move towards achieving the grand vision.

To manage a transition, the current policies must be taken into account, as well as the long-term vision of a country. An understanding of the vertical and horizontal coordination of policies must be achieved, and also the management of a portfolio of options (or technologies), for managing the processes.

4.3.3.2 Strategic Niche Management

Kemp (1994) proposed the notion of Niche Management and described it as a process of “managing the transition towards a more environmentally sustainable energy system,” such *technological transitions* he explains are “*changes in our basic technologies of production, transport and consumption rather than the modifications of existing products or processes or the adoption of end-of-pipe technologies*”. Some examples of the latter include: the installation of pollution control devices and reuse system, the use of more environmentally benign materials, reformulation of existing technologies – sustainable economies.

Policymakers ought to create an environment where technological innovations are incubated and supported by an institutional infrastructure that is dynamic enough to interact with an evolving socio-technical landscape, this policy instrument is strategic niche management (SNM) (Rip & Kemp 1998), defined as “the creation, development, and breakdown of protected spaces for promising technologies” (Kemp *et. al* 2001, p. 270). The management character suggests continuous interaction at the niche level, it is a ‘heuristic

approach' that do not necessarily guarantee success but indeed help create 'points of attachment in an evolving socio-technical landscape' (Rip & Kemp 1998).

Kemp summarizes the aims of SNM as follows (Kemp et al. 1998, p. 186):

- To articulate the changes in technology and in the institutional framework that are necessary for the economic success of the new technology;
- To learn more about the technical and economical feasibility and environmental gains of different technology options, i.e. to learn more about the social desirability of the options;
- To stimulate the further development of these technologies, to achieve cost efficiencies in mass production, to promote the development of complementary technologies and skills and to stimulate changes in social organization that are important to the wider diffusion of the new technology;
- To build a constituency behind a product whose semi-coordinated actions are necessary to bring about a substantial shift in interconnected technologies and practices.

The objective of SNM is therefore to manage the transition process at the niche level and aims to move technological innovations from that level and diffuse them to higher levels, in the MLP approach.

Because in transition management, and SNM more particularly, “experiences inform next steps more than grand visions do” (Kemp and Loorbach 2006), in this dissertation, the LCA model has been incorporated as a sustainability tool. LCA studies will be reviewed and used to ‘understand and learn’ about the technological niches i.e. new, renewable and/or cleaner energy technologies, to assist in constructing transition paths to sustainability for the case study of Saudi Arabia that this dissertation examines. Kemp and Loorbach (2006) explain that “*short-term experiments and actions are derived from the goals and paths and more operationally oriented organization and actors will be involved*” in the process of transition management and/or governance. LCA studies are used as a sustainability tool to construct sustainability transition pathways in the energy sector. (This will be explored and employed in details in chapter 6).

The SNM approach is assisted through creating policy which encourages “learning, maintaining variety (through portfolio management) and institutional change” (Kemp and Loorbach 2006), as well as managing the many interlinked networks and institutions that help provide a supportive environment for technological innovations. Foxon and Pearson (2007) describe how to achieve “*simultaneous achievement of these goals through mutually reinforcing market frameworks and policy instruments, and set out some new institutional arrangements, in energy policy processes.*”

Applying sustainability measures in the energy sector helps identify sustainable energy economy characteristics: (i) economically efficient (‘profit’), (ii) reliable (‘people’), (iii) minimal negative environmental and social impacts (‘planet’), (iv) long term goals, combined with, (v) concrete short term steps (Kemp and Rotmans 2004). Therefore, sustainability meanings are converted into indicators at the patchworks of regime level, such indicators make it easier to track sustainability.

Other modes that manage transition towards sustainability are *reflexive* modes for steering and governance geared toward “*continued learning in the course of modulating ongoing developments rather than the maximization of control to achieve certain outcomes*” (Voß & Kemp 2006 in Kemp & Martens 2007). Kemp & Martens (2007, p. 10) believe that TM is an approach that encourages reflexive governance, as it helps develop sustainability vision and sets transition goals, it therefore employs transition agendas which aim for the establishment, organization, and development of transition arenas (for innovative actors), by the use of ‘transition experiments’ and programs for system innovation, the monitoring and evaluation of the transition process, the creation and maintenance of public support, the practice of ‘portfolio management,’ and the use of learning goals for policy and reliance on circles of learning and adaptation (Rotmans et al. 2001; Kemp & Loorbach 2006; Kemp et al. 2006; Loorbach, 2007).

4.3.4 Reflexive Governance

The quote “Policies for science and technology must always be a mixture of realism and idealism” by Chris Freeman (1991), could suggest that policymaking is best practiced when both elements of realism and idealism are considered. A realistic policy reflects an understanding of the existing state of the country, and an idealistic policy reflects a desired situation of the future. A recently suggested approach to policymaking is reflexive governance (Foxon et al. 2005):

“The challenge of sustainable innovation policy is thus to develop enabling policy frameworks, strategies and processes that support technological and institutional innovation in ways that appropriately encompass the economic, environmental and social dimensions of sustainability”

As part of the ESRC Sustainable Technologies Programme, Foxon et al. (2005) explain that the principles that guide *sustainable innovation* policy include five elements:

1. Stimulate the development of an SI policy regime, bringing together the innovation and environmental policy regimes, by:
 - (i) Making the promotion of sustainable innovation an explicit goal of policy-making;
 - (ii) Facilitating systemic changes in current technological and institutional systems;
 - (iii) Creating a long-term, stable and consistent strategic framework to promote a transition to more sustainable systems;
 - (iv) Formulating clear, long-term sustainability goals.
- 2) Apply systems thinking, engaging with the complexity and systemic interactions of innovation systems and policy-making processes, by:
 - (i) Developing and applying the concept of ‘systems failures’ as a rationale for public policy intervention;
 - (ii) Taking advantage of and encouraging ‘techno-economic’ and ‘policy’ windows’ of opportunity;
 - (iii) Promoting a diversity of technology and institutional options, to overcome ‘lock-in’ of unsustainable technologies and supporting institutions;
 - (iv) Developing and implementing the ‘substitution principle’.
- 3) Advance the procedural and institutional basis for delivery of SI policy aims, by:
 - (i) Promoting public/private institutional structures to enhance regulator/regulated relationships and stakeholder activities;
 - (ii) Ensuring broad stakeholder participation, particularly from the ‘innovation

constituency’.

- 4) Develop an integrated, synergistic mix of policy processes and instruments that cohere to promote sustainable innovation, by:
 - (i) Applying sustainability indicators and sustainable innovation criteria;
 - (ii) Balancing benefits and costs of likely economic, environmental and social impacts;
 - (iii) Using a dedicated SI risk assessment tool in developing policy support instruments;
 - (iv) Assessing instruments in terms of their appropriateness to different stages of the innovation process.
- 5) Incorporate policy learning as an integral part of SI policy process, by:
 - (i) Monitoring and evaluation of policy implementation;
 - (ii) Reviewing policy impacts on sustainable innovation systems;
 - (iii) Learning and policy process enrichment.

Similar work, which relates to guiding innovation policy, is the concept of ‘reflexive governance,’ coined by Kemp and Voß (2005) and Voß et al. (2006). It has been introduced to the literature as *an approach* to transition management. It is a *work-in-progress* approach which offers an insightful tool for ‘guiding’ transition and managing it towards sustainability – it could include scenarios, risk management, and niche-based approaches.

Adrian Smith explains that there is a shift in approach from the 1970s grassroots, individualistic and rebellious character versus today’s policy-minded movement, pedestrian and bureaucratic character. He argues that the ‘break up of linear decision-making may lead to paralysis’ termed the ‘efficacy paradox’ where there is an interplay between questioning and making decision. However, with a shift towards sustainability a multi-domain, multi-level, multi-phase approach is sought after (Rotmans 2002).

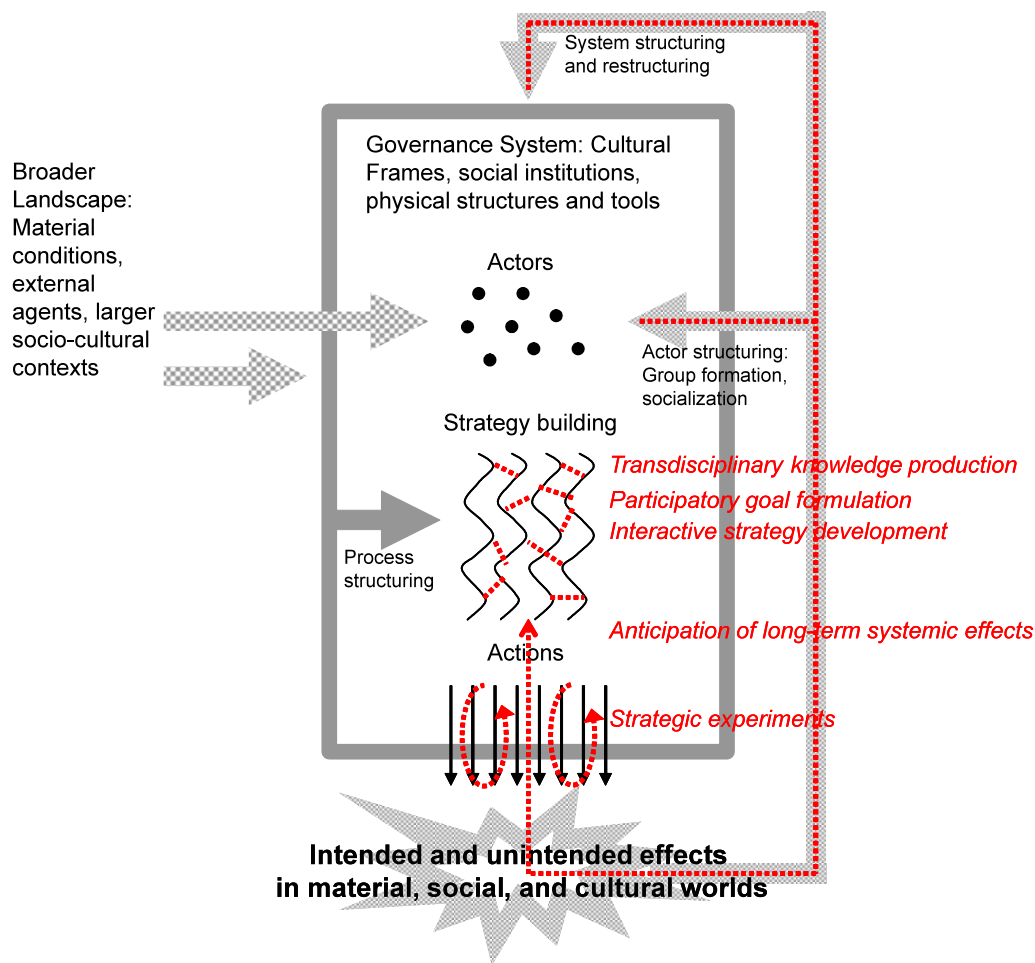


Figure 4-10 Reflexive Governance for Sustainability (Source: Voß and Kemp (2005) based on Burns and Flam 1987)

The figure shows a schematic diagram for the 'reflexive governance for sustainability' framework by Voß and Kemp (2005) based on Burns and Flam (1987). According to this framework, the governance system is composed of cultural frames, social institutions and physical structure and tools. The framework places the 'actors' at the heart of processes; the concept of these actors could be compared to actors in a typical NSI, such as industrial pillars, research centres, and academic institutions.

System building is achieved through *actions*, which are taken as a result of 'strategic experiments'. Such experiments provide feedback and provide learning in the system. Shortcomings of the innovation system approach could be filled by LCA, which provides a feedback loop and therefore inform policy. LCA is a quantitative-based model used extensively in the science and

engineering domain. More recently, it has been used to identify carbon footprint for environmental analysis (LCA will be further explained and discussed in chapter 6).

The nature of such governance is that it is reflexive, or intuitive, in a way that keeps a constant 'restructuring' of the system. The continuous restructuring is a result of interactions across the system, and more specifically based on feedback from results of the system, which amend policy. For example, when employing a framework such as LCA for 'strategic experiments' of technological innovations at the niche level, feedback from such experiments could inform policy, this policy recommendation which is based on experiments may contribute in providing restructuring in the system.

Therefore, reflexive governance could be seen as a policymaking approach that brings together visions of sustainability, NSI, unpacking of MLP, transition management and strategic niche management. It is an approach to works on various levels and across different actors to provide a dynamic and evolving system of governance.

4.4 Discussion on Analytical Frameworks

The chapter examined selective approaches from the vast literature on sustainability, system of innovation, systems innovation, transition management and reflexive governance. A general framework is proposed and used in Chapter 7 and 8, as an integration of the different frameworks and concepts that have been reviewed here, to assist in developing arguments that will answer the research questions. The proposed framework will help (a) materialise a national system of innovation (in chapter 7), (b) construct transition pathways towards sustainability for an oil-based economy (chapter 6 and chapter 8); (c) suggest innovation policy approaches for the objective of spurring/applying technological innovation for clean energy (chapter 6 and 8), and (d) use reflexive governance as an overarching approach to managing a cleaner energy transition towards sustainability (chapter 8).

The following implications that shape the final framework to be used in this dissertation are summarised as follows:

- Technological innovation is placed at the heart of economic development
- Sustainability is a focusing device that defines the direction of development which ought to be sought-after by countries alike, these sustainability objectives will differ depending upon its level of analysis, phase and timescale
- NSI is an important tool to be used for measuring the status of 'innovative capacity' of a country which will ultimately determine the fate of the economy in terms of spurring technological innovation and pursuing sustainability
- NSI includes an intersection between TSI and SSI
- NSI agents include:
 - o Industrial pillars
 - o Education system
 - o Financial system
 - o Research institutions
 - o Institutional set-up
- NSI performance indicators include an intersection between that of TSI [functions] and SSI
- Socio-technical transition paths via system innovations takes a NSI from its current location and places it on a transition path towards sustainability
- Reflexive governance is a form of transition management and provides a good start to initiate the adoption of policies that will assist a country for a transition towards sustainability
 - o Quantitative modelling at the heart of such 'learning' example – LCA studies for energy technologies provide feedback for reflexive governance

To answer the research question, *"How could Saudi Arabia, given its oil-based economy and vast oil reserves, respond to the challenges of climate*

change and the world's transitioning towards environmental sustainability, and away from fossil fuels?" Each conceptual / theoretical framework will be employed to answer a sub-question. As previously explained in Chapter 1, the main research question is divided into five sub-questions:

1. Why is a transition to sustainability in Saudi Arabia important?
2. What is Saudi Arabia's NSI?
3. What is the portfolio of carbon management technologies that could assist Saudi Arabia in such a transition?
4. What might be the socio-technical transition paths that Saudi Arabia could pursue for sustainability?
5. What are the energy and innovation policies that Saudi Arabia could adopt to achieve sustainability?

And the corresponding research objectives are as follows:

- (a) Explain what climate change is and how its global and regional impact affects Saudi Arabia
- (b) To *materialise* the characteristics of a 'national system of innovation (NSI),
- (c) Identify a portfolio of carbon management technologies for KSA
- (d) Construct transition paths for the energy sector towards sustainability
- (e) Recommend technology innovation policy to *spur* energy technology innovation within an economy.

To answer the first question/objective (1/a), it was important to provide an overview of the background presented in chapters 1, 2 and 3. This was achieved by defining the problem statement, providing a literature review and writing an overview on climate change and Saudi Arabia. Therefore, building an argument of the necessity for a transition towards sustainability in Saudi Arabia.

Furthermore, the discussion on sustainability (4.1) in this chapter provides a background on the analytical and theoretical frameworks provided. It presents sustainability as an overarching aim that is motivated by the challenges of

climate change and the current status in Saudi Arabia. The sustainability vision guides the transition pathways towards a cleaner energy economy for Saudi Arabia. Discussing the different levels of sustainability is also important to enable contextualising the forces for Saudi Arabia. For example, global sustainability (4.1.1) places climate change at the macro level as a global driver towards sustainability, whereas the regime sustainability (4.1.2) helps define how to approach sustainability at a country-level using NSI approach, and niche sustainability (4.1.3) is focused on technological innovations and requires developing a portfolio of carbon management technologies that reflect priority technologies in a country. The MLP approach (4.3.1) is used to create these levels of analysis.

The second question/question/objective (2/b) requires materialising a NSI for Saudi Arabia, which could be done through employing the theoretical framework provided in this chapter. The chapter provided a discussion on NSI and a comparison between the different definitions, the actors and functions of NSI defined differently. This will help in identifying the actors of the Saudi NSI and the function of its NSI.

In addition, different efforts to materialise NSI were presented, presenting different indicators, functions and interactions, and processes that manage a NSI. This will be employed to the case study of Saudi Arabia to bring about a definition of its NSI, its actors, functions, elements, interactions and processes.

Moreover, a focus on developing economies NSI was presented; this will be used for Saudi Arabia, to include in its NSI the status of its FDI, education system and innovation policies.

For the third question/objective (3/c), a portfolio of carbon management technologies is necessary to identify the strategic technologies for Saudi Arabia.

The fourth question/objective (4/d), to construct the socio-technical transition paths that Saudi Arabia could pursue for sustainability will be identified by

applying the theoretical and analytical tools and frameworks in this chapter. Namely, using the MLP approach (4.3.1) to deconstruct the sustainability approach, and to identify the transition paths level. Also, the socio-technical transition paths (4.3.2) will be applied to the country case of Saudi Arabia, including the socio-technical regimes in NSI.

To answer the fifth question/objective (5/e), TM (4.3.3) will provide the management approach of NSI and transition pathways and energy and innovation policies. Using the characteristics of TM thinking, and examples of the Dutch transition policies for energy, and the different explanations provided in the literature will help develop the arguments and recommendations for the country case of Saudi Arabia.

The SNM (4.3.3.2) summary will help identify transition pathways of the carbon management technologies identified in the portfolio, one sustainability tool that could be employed is the LCA. This modelling tool has been extensively used in the area and will help create the transition pathways at the micro level using scenarios for energy technological innovations. Further LCA studies could be reviewed to apply it to the country case of Saudi Arabia using the strategic energy technologies for the country.

Reflexive governance (4.3.4) as summarised in this chapter will enable the use of the approach for the country case of Saudi Arabia. This fits well with the other frameworks presented in the chapter. The use of the ESRC sustainable technologies programme, and the framework of reflexive governance for sustainability, reviewed from the literature will help identify what type of governance is needed to adopt innovation policies, and what type of policies are needed to spur carbon management technologies in Saudi Arabia.

4.5 Methodology

Saunders' Research Onion (Saunders et al. 2011) presents a very useful tool for researchers to assist in designing the research.

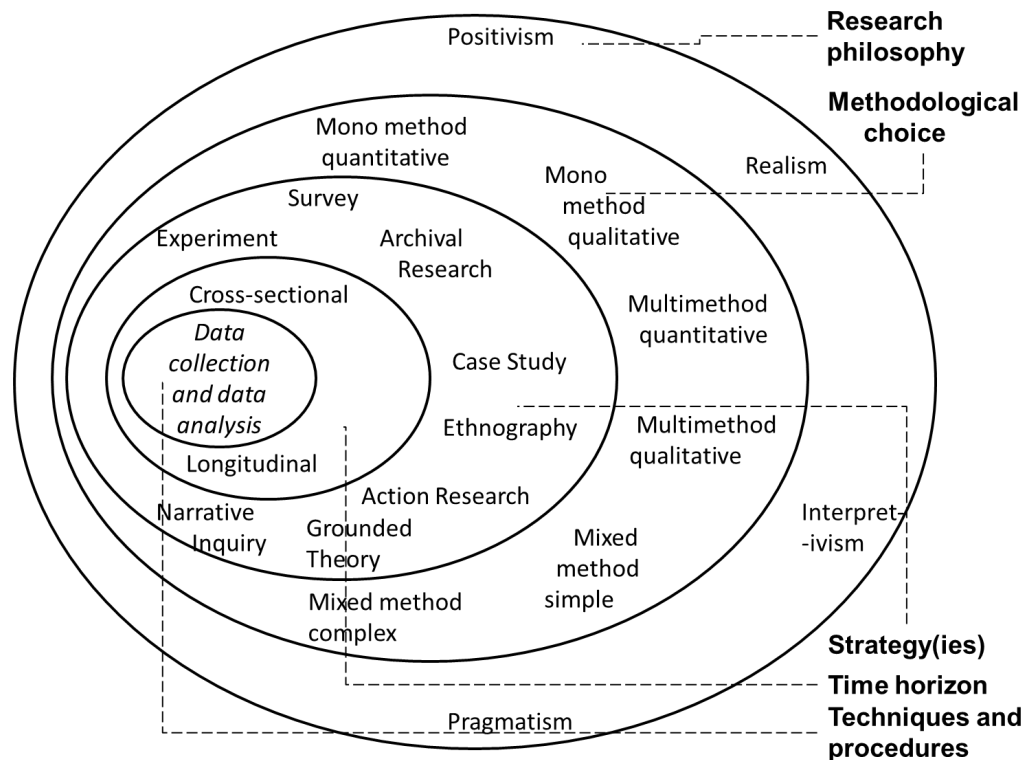


Figure 4-11 The Research Onion (Source: ©Mark Saunders, Philip Lewis and Adrian Thornhill 2011)

In this section, the methodology discussion will follow the diagram above, to cover: the research philosophy, methodological choice, strategy(ies), time horizon, and techniques and procedures.

4.5.1 Research Philosophy

The research philosophy could be explained as philosophical stances or lenses or worldviews that are overarching concepts that determines the understanding of the development of knowledge and the nature of knowledge. The way a researcher look through these lenses to understand human knowledge and the nature of realities is believed to affect the choices he/she make on how to conduct the research.

There are a number of philosophical stances that researchers identified in the research methods literature including, positivism, realism, interpretivism and pragmatism (Saunders *et al.* 2012):

Positivism is typically concerned with cause and effect relations, used in scientific methods where theories are tested with data that are structured, measurable and somewhat predicted, such as large samples of quantitative data and statistical hypothesis.

Realism is also associated with scientific enquiry, however, it states that “reality exists independent of the mind” (Saunders *et al.* 2012), and that the researcher’s senses and own experiences guide them to what is the truth.

Interpretivism is concerned with gathering “rich insights into subjective meanings” (Saunders *et al.* 2012), and is usually related to the study of social phenomena in their natural environment.

Pragmatism is concerned primarily with the consequences of the findings of the research. Usually, no single viewpoint can satisfy the research as it is believed that there are ‘multiple realities’.

The dissertation attests to aspects of both the *interpretive* and *pragmatism* as philosophical stances that guide the research. Interpretive worldview fits with the qualitative part of the dissertation, especially how interviews are designed and how results are analysed. The pragmatic viewpoint will allow the findings from both the quantitative and qualitative studies to be woven into the fabric of the final findings in the Saudi NSI and the construction of transition pathways. Moreover, throughout the research process, there will be many findings that build on each other that will guide the research process as well as the analysis and discussion.

Although this dissertation involves some aspects of positivism, such as the quantitative study and the use of indicators such as carbon dioxide and energy uses and modelling into scenarios, however, such a stance is not

completely fitting with the rest of the dissertation, especially the part on qualitative nature of research.

4.5.2 Methodological Choice

The dissertation uses mixed methods approach as it combines qualitative and quantitative approaches to research, data collection technique and corresponding analysis procedure. There are two complementary studies in this dissertation, the quantitative study that looks into the energy consumption and carbon dioxide emission modelling over a number of scenarios, and the qualitative study which looks into materialising the national system of innovation and constructing transition pathways towards sustainability.



Figure 4-12 The Embedded Design of the Dissertation

The overall design is qualitative and includes a quantitative data collection and analysis and a qualitative data collection and analysis. *See figure above.*

Mixed methods have existed since 1959, and like this dissertation, “many mixed methods studies employ case studies as the qualitative component of the overall design” (Creswell 2003:25). It is believed that more and more researchers are using mixed methods (Tashakkori and Teddlie 1998).

4.5.3 Strategy(ies)

The strategy and research design of the dissertation is a case study with in-depth open-ended interview questions on a selective number of participants. There are many other strategies that could be adopted, such as action

research, using survey strategy to data collection, or ethnography, using experiment and survey research strategies.

4.5.4 Time horizon

The time horizon over which this dissertation will be undertaken is cross-sectional as it aims to answer a question at a particular time, rather than longitudinal which requires data to be collected over an extended period of time.

4.5.5 Techniques and procedures

Data collection and data analysis followed a mixed method approach. More specifically, data collection methods included primary research using LCA studies and construction of scenario, this will be explained in details in chapter 6; and in-depth interviews with selective participants, this will be explained in details in chapter 7, purposive sampling has been employed when selecting the participants in the research for chapter 7. The construction of transition pathways based on findings from both quantitative and qualitative studies will be featured in chapter 8.

The research question is divided into mixed methods research questions, the dissertation integrates both qualitative and quantitative data collection and analysis. The form of data used in both narratives for the qualitative (QUAL) and numeric for the quantitative (QUAN) parts.

The research design is a sequential mixed design, rather than a parallel mixed designs, this is because the QUAN strands of the study occurs before the QUAL strands. The QUAN results are derived from the QUAN results and build upon it.

Triangulation, which is the “use of multiple methods to study a single problem” is employed in this research. This can be explained in the data obtained from the research surveys QUAN and QUAL results of the case study.

The data conversion / transformation / occurred in chapter seven and eight, where QUAN data were converted into narratives to construct transition

pathways for the case study of Saudi Arabia. In addition, the conversion of QUAL data into numbers that can be statistically analysed, such as the order of agents of the NSI.

Inference transferability is applicable in this research as future research may expand the current one to include bigger geographical region, or more variables, or different time, different people, different periods and so on.

The topic at hand is an intersection between two different domains: the social sciences and science and engineering. Different research methodologies and methods are used in these two different disciplines.

5 A Portfolio of Carbon Management Technologies for Saudi Arabia: A Technical Overview

This chapter is the technology chapter and provides a portfolio of carbon technologies for Saudi Arabia, these options are selected to ‘fill the tunnel of the transition pipe’ towards cleaner energy.

Chapter Content:

5 A Portfolio of Carbon Management Technologies for Saudi Arabia: A Technical Overview

5.1 Carbon Capture and Storage

5.1.1 Carbon Capture

5.1.2 Carbon Transport

5.1.3 Carbon Storage

5.1.4 Costs of CCS

5.2 Mineral Carbonation and Industrial Uses of Carbon Dioxide

5.2.1 Mineral Carbonation

5.2.2 Industrial uses of carbon dioxide

5.3 Solar Energy

5.3.1 Solar Photovoltaic

5.3.2 Solar Thermal

5.4 Conclusion

5.1 Carbon Capture and Storage

Carbon Capture and Storage (or Sequestration) denoted hereafter by CCS, is a potentially viable *mitigating* technology that promises to contribute in curbing anthropogenic CO₂ emissions while allowing the continuous use of fossil fuels. It is an increasingly important end-of-pipe technology that promises to reduce CO₂ emissions by 90% in the atmosphere (CCSA 2009) while allowing the continuation of fossil fuel energy systems that are currently locked-in. The importance of CCS technologies stems from the hot debate over the past decade on climate change and the increasing interest in the shift away from fossil fuels. Therefore, CCS is particularly important for the case study of oil-based Saudi Arabia.

The IPCC Special Report on Carbon Dioxide Capture and Storage (IPCC 2005) assesses the current state of CCS and tackles it from a broad range of dimensions, including technical, scientific, environmental, economic and societal (IPCC 2005). According to this study, a CCS system is:

“A process consisting of the separation of CO₂ from industrial and energy-related sources, transport to a storage location and long-term isolation from the atmosphere. This report considers CCS as an option in the portfolio of mitigation actions for stabilization of atmospheric greenhouse gas concentrations” (IPCC 2005).

The three stages of carbon capture, carbon transport and carbon storage or sequestration will be discussed below:

5.1.1 Carbon Capture

The purpose of carbon capture is to create a collection point for carbon dioxide for later transportation and storage. Carbon capture will most likely be applied to large sources of CO₂, as the report suggests, such as: industrial plants including the manufacturing of iron, steel, cement and bulk chemicals. This approach is the easiest because it is capturing a huge amount of CO₂ and from a fixed location. On the other hand, capturing from small and mobile sources is expected to be difficult (Thambimuthu *et al.* 2005 in IPCC 2005).

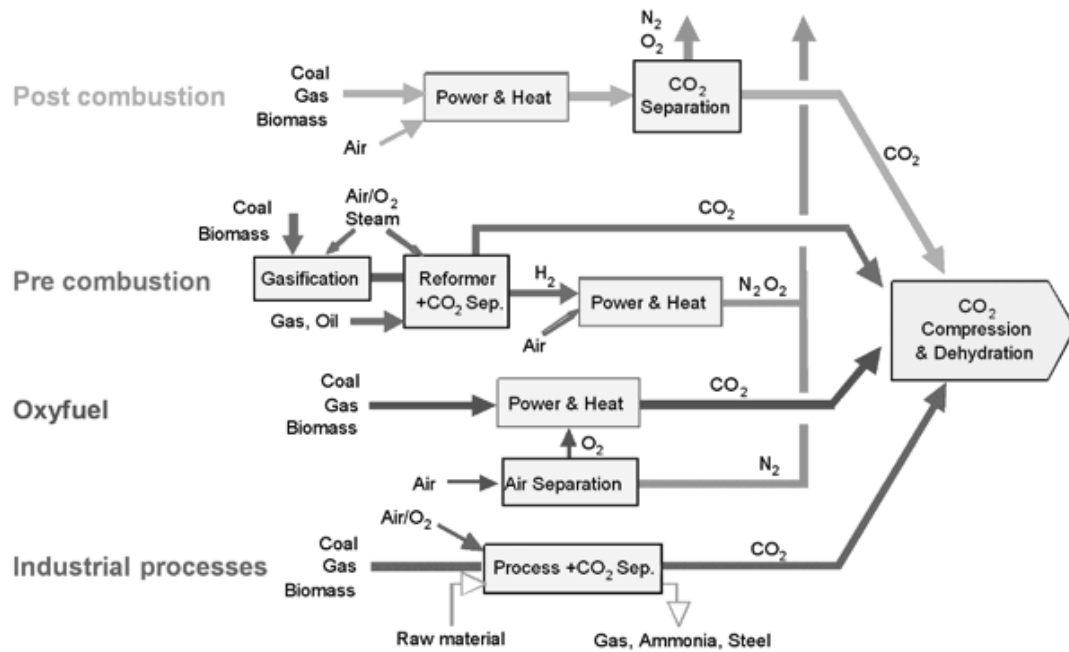


Figure 5-1 CO₂ Capture Systems (Source: Adapted from BP cited in Thambimuthu *et al.* 2005, IPCC 2005)

There are four types of carbon capture system as shown on Figure 5-1 (Thambimuthu *et al.* 2005, IPCC 2005):

(i) Industrial separation

Carbon capture from industrial process stream has been going on for 80 years (Kohl and Nielsen 1997 cited in IPCC 2005), for example, natural gas purification, production of hydrogen-containing synthesis gas for the manufacture of ammonia, alcohols and synthetic liquid fuels. However, such applications do not intend to store or use CO₂ and therefore most of the capture CO₂ is vented to the atmosphere (Thambimuthu *et al.* 2005, IPCC 2005).

(ii) Post-combustion

The post-combustion capture system is the first one shown in Figure 5-1, the CO₂ separation is done after the energy generation, as the name suggests, post-combustion capture of CO₂ occurs *after* the combustion (burning) of fossil fuels and biomass, but instead of the flue gases discharged to the atmosphere, it is rather passed through an equipment which separate most of

the CO₂. The CO₂ in turn is then safely stored into a reservoir and the remaining flue gas is released into the atmosphere (Thambimuthu *et al.* 2005, IPCC 2005).

According the IPCC report (Thambimuthu *et al.* 2005, IPCC 2005), these systems of reference represent high efficiency power plant technology where such capture is best applicable, for example: the oil, coal and natural gas power plants of a total installed capacity of 2261 GW (IEA WEO 2004), especially the supercritical pulverized coal fired plants of 155 GW (IEA CCC 2005 in Thambimuthu *et al.* 2005 in IPCC 2005), and the natural gas combined cycle (NGCC) plants of 339 GW (Thambimuthu *et al.* 2005, IPCC 2005).

(iii) Oxy-fuel combustion

The oxy-fuel combustion system uses (nearly pure) oxygen (O₂), instead of air, for the combustion, which results in CO₂ / H₂O-rich flue gas, hence, H₂O can conveniently be recycled into the combustor to balance the excessive heat created by burning the fuel in pure oxygen. This is shown as the third system in Figure 5-1. The air separation occurs outside the system and O₂ is injected in the energy generation process. The systems of reference for this approach are the same as those in (ii) for post-combustion systems (Thambimuthu *et al.* 2005, IPCC 2005).

(iv) Pre-combustion

As the name suggests and as shown in the second system in Figure 5-1, CO₂ is separated before the combustion occurs. This system involves reacting a fuel with oxygen or air and/or steam to give an output of synthesis gas (syngas) or flue gas composed of carbon monoxide and hydrogen. The carbon monoxide reacts with steam in a catalytic reactor to produce CO₂ and more Hydrogen. CO₂ is separated from the reformer and hydrogen (H₂-rich fuel) is injected to the energy generation process, for example in applications such as boilers, furnaces, gas turbines, engines and fuel cells (Thambimuthu *et al.* 2005, IPCC 2005).

The systems of reference here are oil and coal-based that are of 4 GW capacity, integrated gasification combined cycles (IGCC) amounting to 0.1% of the total 3,718 GW installed capacity worldwide (IEA WEO 2004 cited in Thambimuthu *et al.* 2005, IPCC 2005).

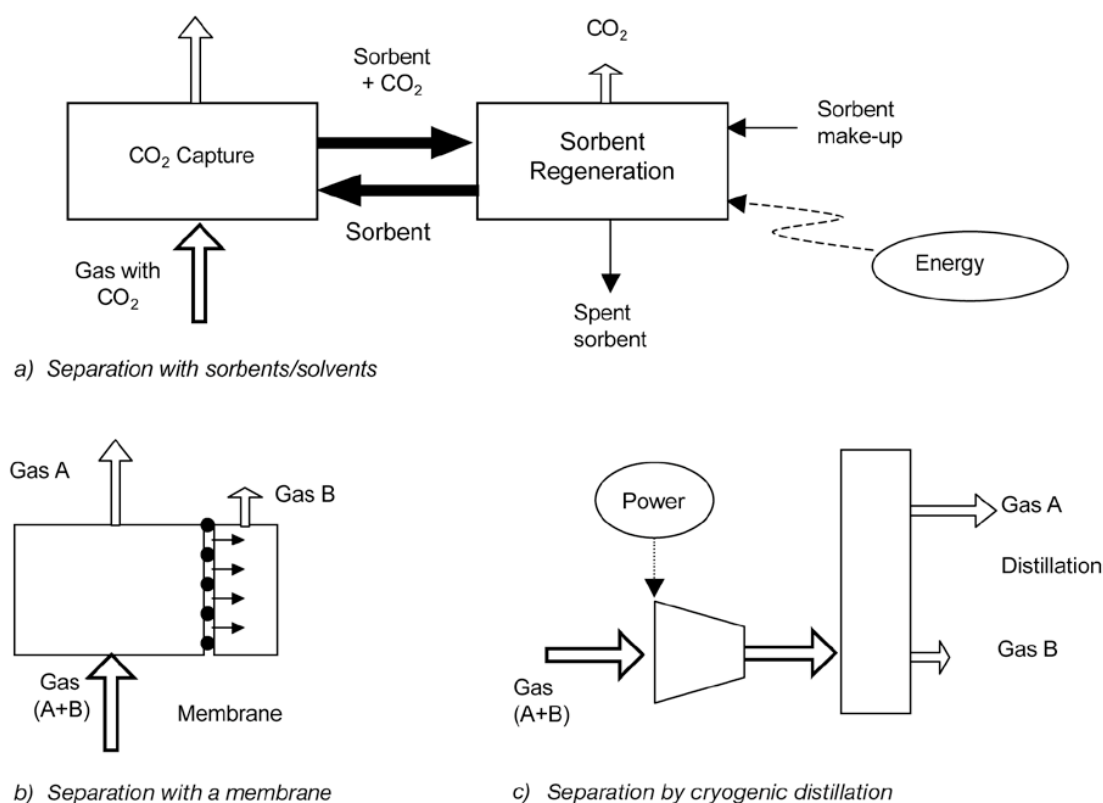


Figure 5-2 Separation Methods for CO₂-Containing Gas (Source: IPCC 2005)

The separation of CO₂-containing gas is done via a number of approaches, including the following three, shown in Figure 5-2 consecutively:

a) Separation with sorbents/solvents

As shown in Figure 5-2.a the sorbent regeneration is the main process, the separation is achieved by passing the CO₂-containing gas into a liquid or solid sorbent, which captures CO₂. The CO₂-containing gas is transported to the sorbent regeneration where it is exposed to high temperature (which changes the pressure and other conditions in the sorbent) that causes the separation of CO₂ from the sorbent, the sorbent is then re-injected to capture more CO₂ to repeat the cycle of separation. In some cases, the sorbent comes in solid

form but performs the same functions without being re-injected to CO₂ capture, in this case, a fresh sorbent stream is injected instead (Thambimuthu *et al.* 2005, IPCC 2005).

The problem with this system is the large flow of sorbent between the vessels, and therefore, it requires large equipment size and high level of energy for sorbent regeneration. The sorbent material performance varies, the good performance sorbent are purchased at more expensive prices but perform better under high CO₂ loading gas and repetitive cycles. Hence, this increases the overall cost of the system (Thambimuthu *et al.* 2005, IPCC 2005).

b) Separation with membranes

Membranes are materials specially manufactured to allow through it a selective permeation of a gas, materials can be polymeric, metallic or ceramic. The process is usually driven by different pressure points across the membrane, which enables the separation of a gas stream that passes through it. As shown in Figure 5-1.b the CO₂-containing gas is passed through the membrane where it is exposed to different pressure levels that eventually separate the CO₂ to form a concentrated gas (Thambimuthu *et al.* 2005, IPCC 2005).

There is a number of commercial applications to membrane separation today, for example, CO₂ separation from natural gas. However, this system has not yet been applied at large scale but is being researched worldwide to manufacture more suitable membrane material for large-scale application (Thambimuthu *et al.* 2005, IPCC 2005).

c) Distillation of a liquefied gas stream and refrigerated separation

The gas is liquefied through a series of compression, cooling and expansion processes. As can be seen in Figure 5-1.c, once the gas is liquefied, it is then passed to a distillation column where the gas components can separate (Thambimuthu *et al.* 2005, IPCC 2005).

This system is currently commercially available at large scale. Oxygen is separated from air and could then be used in a range of capture system (as explained in b & c, oxy-fuel combustion and pre-combustion systems) (Thambimuthu *et al.* 2005, IPCC 2005).

Refrigerated separation can also be applied for the separation of CO₂ from other gases, such as separating impurities from purer CO₂ streams. For example, from oxy-fuel combustion, and for the removal of CO₂ from natural gas or synthesis gas after the conversion of CO to CO₂ (Thambimuthu *et al.*, 2005 IPCC, 2005).

5.1.2 Carbon Transport

The purpose of carbon transport is straightforward: to transfer the captured carbon (in gas, liquid or solid form) from its source location to the storage location (geological or oceanic). This is done in two ways, either through pipelines or shipping. Such technology commercially exists today in the oil and gas industry and has been in use for a long time (Doctor *et al.* 2005 in IPCC 2005).

The transport system, of pipelines and ships, is governed by a framework of rules and regulations that protect the surrounding environment as well as the public. Therefore, it is important to consider these measures at the design stage and the use of these systems.

5.1.2.1 Pipeline Systems

These issues must be taken into consideration when using the pipeline system for transporting CO₂. This is explained by the nature of CO₂ and its characteristics which might react with the steel in the pipelines, for example, one must consider the corrosion rate of carbon steel, the water solubility limit in high pressure, and what other chemicals are also found in the pipeline that might react as well. Therefore, it is advised to have a CO₂ stream that is dry and free of hydrogen sulphide to avoid corrosion; there is also some minimal specification for 'pipeline quality' (Doctor *et al.* 2005 in IPCC 2005).

Pipeline for CO₂ transport has been used for a long time, the IPCC report states that in fact they now extend to over 2,500 km in western USA transporting 50 MtCO₂ y⁻¹ from natural resources and for enhanced oil recovery (EOR) projects in west Texas. However, it is argued (Doctor *et al.* 2005 in IPCC 2005) that it is possible to design a corrosion-resistant pipeline that overcomes these challenges.

Current use of pipeline systems includes the routinely transported liquefied natural gas (LNG) and liquefied petroleum gas (LPG) such as propane and butane by marine tankers.

5.1.2.1.1 Current pipeline transport system:

1. Canyon Reef

This is the first large CO₂ pipeline in the USA built in 1970 by the SACROC Unit in Scurry County, Texas. It is 352 km long with 12,000 tonne capacity, it operates daily from Shell Oil Company to move 12,000 tonnes of anthropogenically produced CO₂, equivalent to 4.4 Mt y⁻¹ (Doctor *et al.* 2005 in IPCC 2005).

2. Bravo Dome Pipeline

Constructed by Oxy Permian, this pipeline connects the Bravo Dome CO₂ field with other major pipelines, it is 20 inch thick and has a 7.3 MtCO₂ yr⁻¹ capacity and operates by Kinder Morgan (Doctor *et al.* 2005 in IPCC 2005).

3. Cortez Pipeline

This line starts at Cortez, Colorado, across the Rocky Mountains and connects to other CO₂ lines. It is 801 km long and 30 inch thick with an approximate capacity of 20 Mt CO₂ yr⁻¹, it was built in 1982 to supply CO₂ from the McElmo Dome in S.E. Colorado to the CO₂ hub at Denver City, Texas (Doctor *et al.* 2005 in IPCC 2005).

Today, there are many operating long-distance CO₂ pipelines, in North America these add to a total length of 2,591 km and a capacity of 49.9 MtCO₂ yr⁻¹ (Doctor *et al.* 2005 in IPCC 2005).

5.1.2.2 Shipping

The existing shipping technology for hydrocarbons is the same one to be used for shipping CO₂ (in gas, liquid or solid forms).

5.1.3 Carbon Storage

The IPCC report (2005) concludes that the capture technologies, for example, one process is natural gas sweetening which is already being used in two industrial plants for CO₂ capture and storage at a capacity of 2 MtCO₂ yr⁻¹. Also, in ammonia production CO₂ is already being separated. Hence, together both natural gas sweetening and ammonia plants CO₂ capture capacity is over 7 MtCO₂ yr⁻¹ with some CO₂ storage for EOR projects. In addition, potential exists for cement and steel production plants, but these have not been applied to yet.

5.1.3.1 Carbon Geological Sequestration:

Carbon Geological Sequestration (GS) is a process by which carbon is injected into deep geological formation of greater than 1 km depth for the purpose of trapping CO₂ away from the atmosphere. Potential sites for geological sequestration include: depleted oil and gas reservoirs, saline aquifers, and coal seams that cannot be mined (Wilson and Gerard 2007).

There is a number of geological options for carbon sequestration, the most obvious ones are oil and gas wells.

5.1.3.1.1 Current Projects

The following table provides an overview of the current CO₂ geological sequestration demonstration projects (Wilson and Gerard 2007).

Table 5-1 CO₂ Geological sequestration demonstration projects (Source: IEA 2004, and Service 2004 cited in Wilson and Gerard, 2007)

Project	Start	Type of Project	Participants and Location	Tons/CO ₂ Injected/Yr	Total Tons CO ₂ To Be Injected
Sleipner	1996	Upstream natural gas	Statoil project, North Sea	1 Mt	20 Mt
Weyburn	2000	CO ₂ from anthropogenic source, enhanced oil recovery	EnCana, Canada	1 Mt	20 Mt
In Salah	2004	Upstream natural gas	BP and Sonatrach, Algeria	1 Mt	18 Mt
Snohvit	Planned 2006	Upstream natural gas/LNG	Statoil, Petroro, TotalFinaElf, and others, Barents Sea	0.7 Mt	
Gorgon	2008-2010	Upstream natural gas/LNG	ChevronTexaco	1 Mt in Phase I	125 Mt

CO₂-EOR technologies have been demonstrated at commercial scale for over 30 years in the Permian Basin of West Texas and Eastern New Mexico. Today, in the US 105 CO₂-EOR projects provide nearly 250,000 barrels per day of incremental oil production in the U.S. (ARI 2010) See table below:

Table 5-2 Volumes of CO₂-Supplying EOR Projects in 2008 (Source: ARI 2010)

State/Province (Storage location)	Source Type (location)	CO ₂ Supply (million tonnes/year)		CO ₂ Supply (MMcfd)	
		Natural	Anthropogenic	Natural	Anthropogenic
Texas-Utah-New Mexico-Oklahoma	Geologic (Colorado-New Mexico) Gas Processing (Texas)	28	2	1,455	80
Colorado-Wyoming	Gas Processing (Wyoming)		4		230
Mississippi	Geologic (Mississippi)	15		800	
Oklahoma	Fertilizer Plant (Oklahoma)		1		35
Michigan	Gas Processing (Michigan)		<1		15
Saskatchewan	Coal Gasification (N. Dakota)		3		150
TOTAL		44	10	2,255	510

Source: Brian Harrove, I. Stephen Melzer, and I on Whitman "A Status Report on North American CO₂-EOR Production and CO₂

The Scottish Centre for Carbon Storage, School of Geosciences, University of Edinburgh has developed a CCS map online (GEOS 2009) displaying and account of the world's CCS activities, it locate sites, which are currently injecting CO₂, planned CCS sites (injecting at least 700,000 tonnes CO₂ per year), and sites which have been cancelled or have completed injection.

As presented in the CCS map (GEOS 2009) there are about 14 sites that are currently injecting CO₂, these include:

1. Sleipner West
 - a. Location: Offshore North Sea, Norway
 - b. Company: Statoil
 - c. Status: Operational
 - d. Operational Date: 1996
 - e. Separation Technology: n/a. Amine scrubbers. CO₂ removed from natural gas stream
 - f. Injection: 2,800 tonnes CO₂ separated and injected daily.
2. Weyburn-Midale Project
 - a. Location: Saskatchewan, Canada
 - b. Company: EnCana, Apache and Shell
 - c. Status: Operational
 - d. Operational Date: 2000
 - e. Separation Technology: Post combustion – Cold methanol wash
 - f. Injection: about 2 million tonnes per year (varies)
3. In Salah
 - a. Location: In Salah gas field, Central Sahara region, Algeria
 - b. Company: BP, Sonatrach & Statoil
 - c. Status: Operational
 - d. Operational Date: 2004
 - e. Separation Technology: Post combustion amine
 - f. Injection: 1.2 million tonnes CO₂ per year. 17 million tonnes estimated to be stored over project life.
4. K12-B
 - a. Location: K-12B gas field. Dutch sector of North Sea, 150 km north west of Amsterdam, The Netherlands
 - b. Company: Dutch Ministry of Economic Affairs, Gas de France Production Nederland B.V. and TNO
 - c. Status: Operational
 - d. Operational Date: 2004
 - e. Separation Technology: n/a. Amine scrubbers. CO₂ removed from natural gas stream
 - f. Injection: currently stored 60,000 tonnes CO₂. Injection still occurring at approximately 20,000 tonnes per year.
5. Snøhvit
 - a. Location: Offshore Barents Sea, Norway
 - b. Company: Statoil
 - c. Status: Operational
 - d. Operational Date: 2007
 - e. Separation Technology: n/a – Amine Scrubbers
 - f. Injection: Gas production on Snøhvit expected to reach 6.9 billion m³ per yr. Approximately 700,000 tonnes CO₂ to stored annually.
6. La Barge

- a. Location: Wyoming
 - b. Company: ExxonMobil
 - c. Status: Operational
 - d. Separation Technology: from gas production, stored in depleted gas reservoirs
 - e. Injection: Capture 4 million tonnes CO₂ annually.
 - f.
7. Huaneng Gaobeidian
- a. Location: Beijing, China
 - b. Company: CSIRO (Australia), Huaneng Group (China) & Thermal Power Research Institute (TPRI)
 - c. Status: Operational
 - d. Operational Date: 2008
 - e. Separation Technology: Post combustion- 'amine based pilot plant'
 - f. Injection: Capture 3000 tonnes CO₂ annually.
8. Otway project
- a. Location: Otway Basin, South Western Victoria, Australia
 - b. Company: CO2CRC – supported by 15 companies & 7 government agencies
 - c. Status: Operational
 - d. Operational Date: 2008
 - e. Separation Technology: CO₂ bought in
 - f. Injection: 65,000 tonnes CO₂ injected over 2 years
9. Hazlewood Carbon Capture Project
- a. Location: Hazlewood Power Station, Victoria, Australia
 - b. Company: CO2CRC, Loy Yang Power, International Power and CSIRO
 - c. Status: Operational
 - d. Operational Date: 2009
 - e. Separation Technology: PCC (post combustion capture)
 - f. Injection: 10,000-20,000 tonnes CO₂ per annum
10. Loy Yang PCC Project
- a. Location: Latrobe Valley, Victoria, Australia
 - b. Company: CO2CRC, Loy Yang Power, International Power and CSIRO
 - c. Status: Operational
 - d. Operational Date: 2008
 - e. Separation Technology: PCC (post combustion capture)
 - f. Injection: 1,000 tonnes CO₂ per annum.
 - g.
11. Munmorah PCC Project
- a. Location: Munmorah Power Station, near Tuggerah Lakes, New South Wales, Australia
 - b. Company: Delta Electricity, CSIRO & ACA
 - c. Status: Operational
 - d. Operational Date: 2009

- e. Separation Technology: Post carbon capture (PCC) ammonia absorption process
 - f. Injection: to be released to atmosphere at the pilot phase. Geological injection will occur at next demo phase.
12. Wandoan Project
- a. Location: Queensland, Australia
 - b. Company: GE Energy, Stanwell and XStrata Coal
 - c. Status: In Planning
 - d. Operational Date: 2016
 - e. Separation Technology: IGCC
 - f. Injection: -
13. Schwarze Pumpe
- a. Location: Schwarze Pumpe, Brandenburg, Germany
 - b. Company: Vattenfall / Gas de France
 - c. Status: Operational
 - d. Operational Date: 2008
 - e. Separation Technology: Oxyfuel
 - f. Injection: 100,000 tonnes CO₂ over 3 years.
14. The Southwest Regional Partnership
- a. Location: near Price, Utah, USA
 - b. Company: Various
 - c. Status: Operational
 - d. Operational Date: 2008
 - e. Separation Technology: -
 - f. Injection: Phase III: injection schedule will lead up to 900,000 tonnes CO₂ over 4 years from 2008-2011

There are many planned projects for CCS around the world, amongst which is an announcement by the Saudi assistant petroleum minister (Reuters 2009): Saudi Arabia is working on its first demonstration project for CO₂ enhanced oil recovery (EOR) by 2013 in the world's largest oilfield, Ghawar, which produces 5 million barrels per day, about half of Saudi oil production.

According to the IPCC Special Report on Carbon Dioxide Capture and Storage (IPCC 2005), all components of CCS Technologies are currently being used in industrial operations, however, they are not used for CCS. The maturity of components of CCS technologies are presented in the report:

Table 5-3 Maturity of CCS System Components (Source: Rubin *et al.* 2005, p. 21)

CCS component	CCS technology	Research phase	Demonstration phase	Economically feasible under specific conditions	Mature market
Capture	Post-combustion			X	
	Pre-combustion			X	
	Oxyfuel combustion		X		
	Industrial separation				X
Transportation	Pipeline				X
	Shipping			X	
Geological storage	Enhanced Oil Recovery (EOR)				X
	Gas or oil fields			X	
	Saline formations			X	
	Enhanced Coal Bed Methane recovery (ECBM)*		X		
Ocean storage	Direct injection (dissolution type)	X			
	Direct injection (lake type)	X			
Mineral carbonation	Natural silicate minerals	X			
	Waste materials		X		
Industrial uses of CO ₂					x

Key:

Research phase: means that the basic science is understood, but the technology is currently in the stage of conceptual design or testing at the laboratory or bench scale, and has not been demonstrated in a pilot plant.

Demonstration phase: means that the technology has been built and operated at the scale of a pilot plant, but further development is required before the technology is ready for the design and construction of a full-scale system.

Economically feasible under specific conditions: means that the technology is well understood and used in selected commercial applications, for instance if there is a favourable tax regime or a niche market, or processing on in the order of 0.1 MtCO₂ yr⁻¹, with few (less than 5) replications of the technology.

Mature market: means that the technology is now in operation with multiple replications of the technology worldwide.

+ **CO₂ injection for EOR** is a mature market technology, but when used for CO₂ storage, it is only economically feasible under specific conditions.

* **ECBM** is the use of CO₂ to enhance the recovery of the methane present in unmineable coal beds through the preferential adsorption of CO₂ on coal. Unmineable coal beds are unlikely to ever be mined, because they are too deep or too thin. If subsequently mined, the stored CO₂ would be released.

In 2005, a study was conducted for DTI Cleaner Fossil Fuels Programme to investigate the potential role for Carbon Abatement Technologies in the UK to

help achieve their carbon reduction objectives of 60% by 2050. The study used the MARKAL energy systems model to explore the possible scenarios for future economic growth, demand for energy related services, primary energy prices, social preferences and the availability of other low carbon technologies. The outcome of this study concluded that for the deployment of CCS technologies, the earliest implementation is in 2010 under the World Markets Scenario that involved the highest rate of economic growth, and in 2020 in lowest growth rate Baseline and Global Sustainability Scenarios. In addition, the study has concluded that the costs and performance of CCS technologies remain uncertain (DTI 2005).

Stage of CCS component technologies

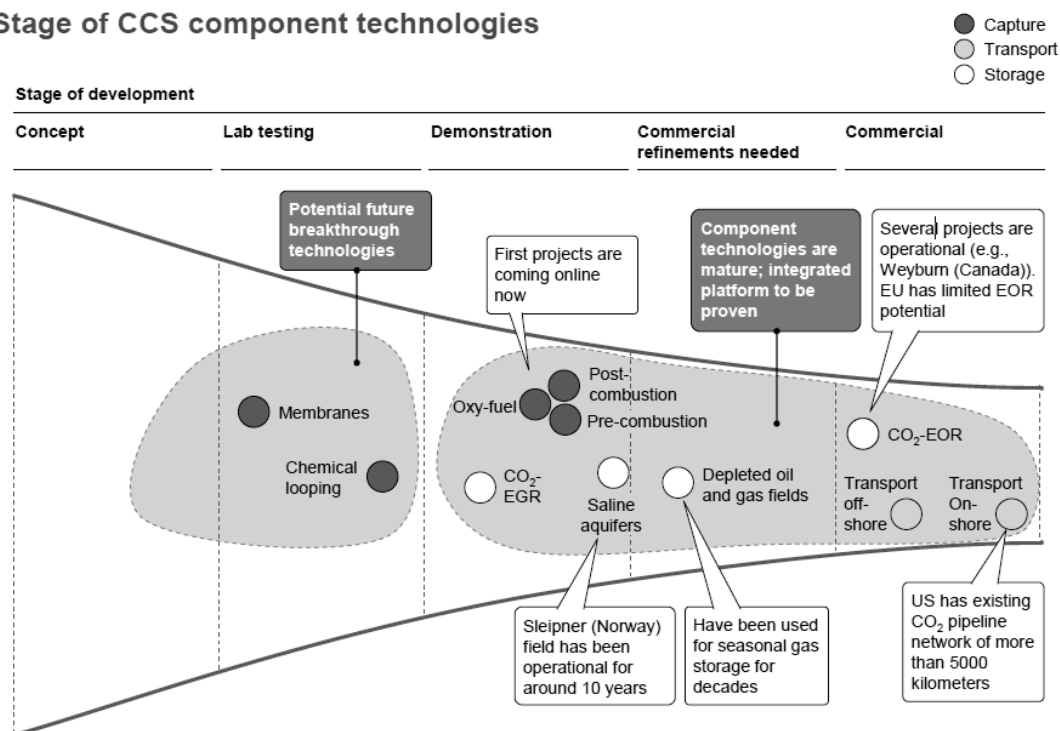


Figure 5-3 Stages of CCS component technologies (Source: McKinsey & Company - Naucier et al. 2008)

The figure above shows another diagram that presents the stages of CCS component technologies and their development status. It shows that there are some capture technologies that remain in the lab testing stage, these are the membranes technology and chemical looping, these also represent potential future breakthrough technologies. In the demonstration phase, there are other capture technologies such as post-combustion, pre-combustion and oxy-fuel;

the storage technology of CO₂-EGC and saline aquifers are also in the demonstration stage, these are being demonstrated at the Sleipner (Norway) field which has been operating for the past decade. In the commercial (with refinements needed) stage, there is a storage technology for depleted oil and gas fields, these have also been in use for seasonal gas storage for decades. The commercial stage constitutes CO₂-EOR and transport, off-shore and on-shore.

The Global CCS Institute was created as a direct result of the G8 declaration to launch 20 demonstration projects by 2010, in their first published report a detailed account of all CCS projects around the world was created, according to it, there is a total of 275 projects, 213 active or planned, 101 commercial scale, 62 integrated, 34 completed, 26 cancelled, and 2 withheld (p. 4). Post-combustion capture method is the predominant capture method being pursued by proponents, 48% of the active/planned projects use this method; Pre-combustion capture method is used by 35% of the active/planned projects; Oxy-fuel combustion technology accounts for 9% of projects.

5.1.4 Costs of CCS

Table 5-4 Cost of Electricity with CCS for Coal and Natural Gas Systems (Source: Spath and Mann 2004)

System	Cost of electricity (¢/kWh)				
	Prior to CO ₂ sequestration	Cost of CO ₂ capture & compression	Cost of CO ₂ transport & storage	Cost of replacement power	Total cost
Coal-fired	2.5	2.8	0.9	1.1	7.3
NGCC	4.5	1.7	0.6	0.7	7.5

The above table shows the costs of introducing CCS to electricity generation in two systems, coal-fired power plants (coal-fired) and natural gas combined cycle (NGCC)-fired power plants. The cost of electricity is shown in cent per kilowatt-hour (¢/kWh), the first column shows the cost prior to applying CCS technologies to electricity generation, for coal-fired this it is 2.5 ¢/kWh and for NGCC it is 4.5 ¢/kWh. The last column on the right shows total cost after CCS, including CO₂ capture and compression, CO₂ transport and storage and replacement power, total costs for Coal-fired and NGCC it arrives at 7.3 and

7.5 ¢/kWh, respectively. This is an increase in cost at about 66% for coal-fired and 40% for NGCC (Spath and Mann 2004).

Based on the results of major economic studies available in the literature (Herzog and Golob 2004) adjusted to a common economic basis, Figure 5-4 summarizes the present cost of electricity (COE) from three types of CO₂ capture power plants: Integrated Gasification Combined Cycles (IGCC), Pulverized Coal Fired Single Cycle (PC), and Natural Gas Combined Cycles (NGCC). The mean and range (plus/minus one standard deviation) are shown for each capture plant, along with a typical COE for a no capture plant. This results in an increase in the cost of electricity of 1-2¢/kWh for an NGCC plant, 1-3¢/kWh for an IGCC plant, and 2-4¢/kWh for a PC plant.

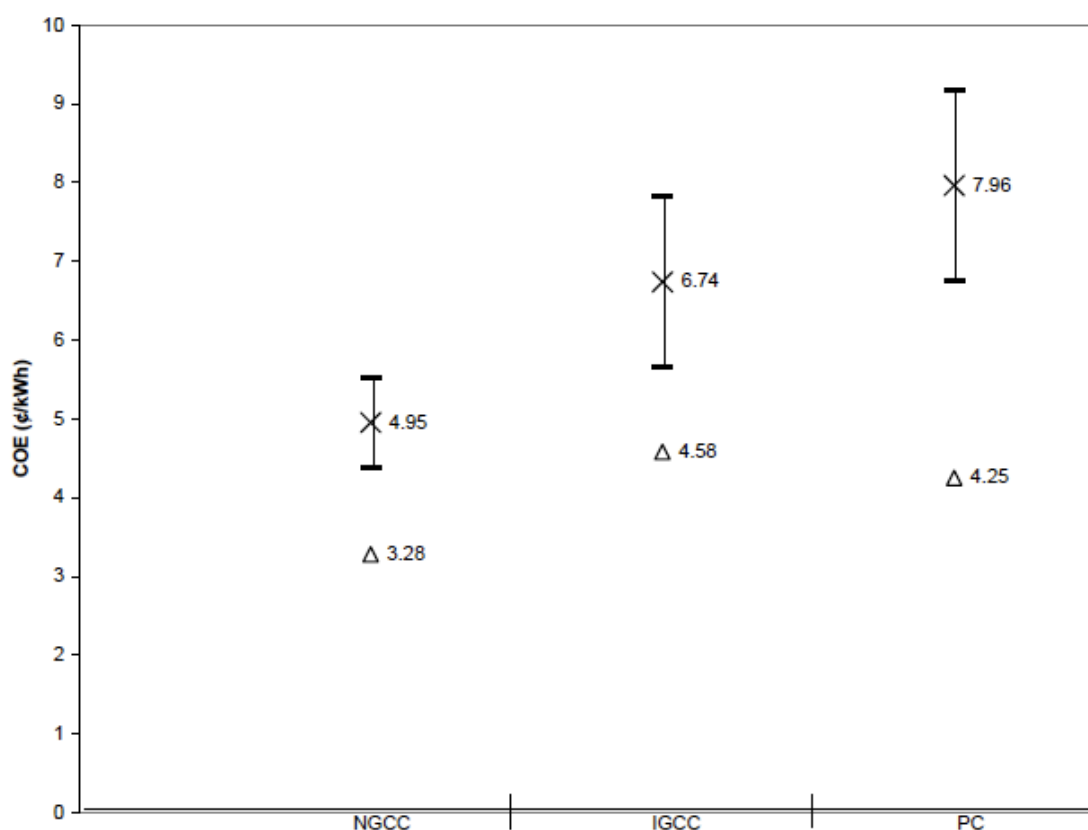


Figure 5-4 Cost of electricity with CO₂ capture for fossil fuel power plants (Source: Herzog and Golob 2004)

Therefore, installing CCS systems to power energy systems will ultimately increase the cost typically by 40-60% as shown above, but it will also reduce carbon dioxide emissions greatly. This is further explored in the next chapter.

5.2 Mineral Carbonation and Industrial Uses of Carbon Dioxide

Amongst other options for carbon management comes two rather different approaches presented in the IPCC Special Report on CCS (2005): (i) the fixation of CO₂ in the form of mineral carbonation, and (ii) the industrial utilization of CO₂ as a feedstock for carbon-containing chemicals. These technologies are still immature but provide a great potential for carbon sequestration.

5.2.1 Mineral Carbonation

Sequestering carbon in solid form (Lackner *et al.* 1996, 1997, 1999 in Edmonds *et al.* 2001) as a means to mimic natural processes is often attributed to Seifritz (1990) and Dunsmore (1992). However, it was Lackner *et al.* (1995) that provided extensive and useful research, which forms the building blocks of today's research in mineral carbonation (Herzog 2002).

Mineral Carbonation is “the fixation of CO₂ in the form of inorganic carbonates” (Mazzotti *et al.* 2005). It may also be called ‘mineral sequestration’ or ‘carbonate disposal’ – the objective is to store carbon dioxide away from the atmosphere, to reduce the overall carbon dioxide emissions, and store it in the form of solid minerals in geological underground. This mimics the natural process of mineral carbonation which is called ‘silicate weathering’ and takes a long time at geological timescales (Seifritz 1990, Mazzotti *et al.* 2005), Lackner *et al.* (1997) explains that with mineral carbonation one could speed up the natural process from hundred thousands of years to only 30 minutes.

The process of mineral carbonation is based on the chemical reaction of CO₂ with metal oxide bearing materials, these are abundantly available in nature, to form insoluble mineral carbonates. Amongst the elements that form stable mineral carbonates, only Calcium (Ca), Magnesium (Mg) and Iron (Fe) are worth researching due to their abundant availability in nature. In fact, Ca and Mg can be found in quantities much larger than would be required to sequester all the CO₂ that could be released to the atmosphere from burning all the available fossil fuels (Lackner *et al.* 1997).

The figure below shows the process of utilizing the energy by-product of CO₂ into the mineral carbonation process. As the figure shows, there are also energy requirements as well as wastes from this process. Hence, it suggests that a LCA study is especially essential for this option.

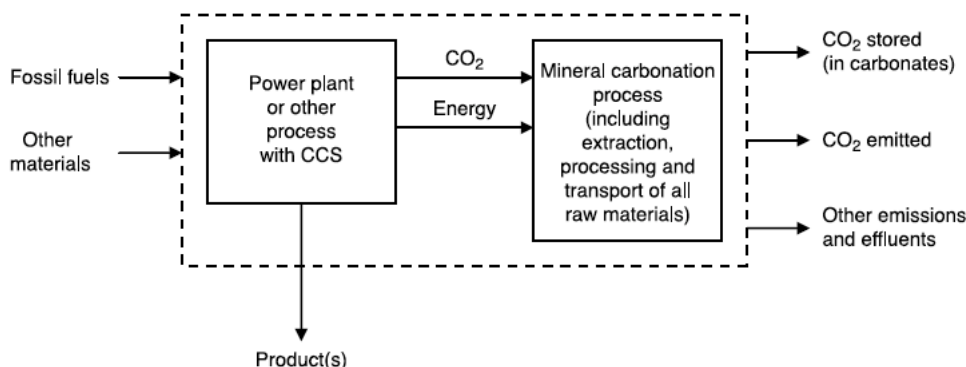


Figure 5-5 A Schematic Diagram for Material and Energy Balances through Carbon Mineralisation (Source: Mazzotti *et al.* 2005, p. 322)

The process of mineral carbonation via magnesium mineral is shown in the diagram:

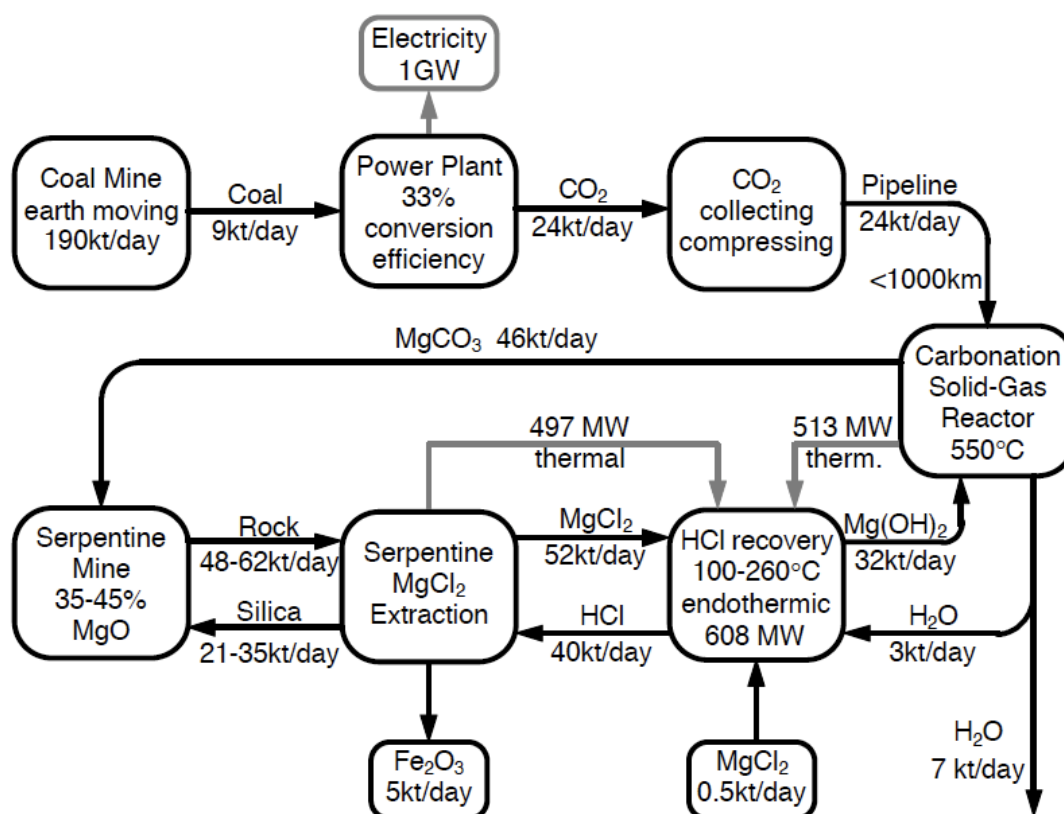


Figure 5-6 Carbonation via Magnesium Hydroxide (Source: Lackner *et al.* 1997, p. 18)

Figure 5-6 above explains the mass flows in the combined, coal mining, power plant and carbon dioxide removal operation. The numbers indicate the overall mass flow for a gigawatt power plant with a conversion efficiency of 33%. There are four main stages of the process (Lackner *et al.* 1997):

1. Mining, crushing and milling of serpentines or peridotite rock
2. Acid extraction of magnesium from the ore
3. Recovery of the hydrochloric acid and formation of magnesium hydroxide
4. Direct carbonation of magnesium hydroxide at elevated temperatures

There are three main advantages assessed in Herzog (2002) that must be taken into consideration for mineral carbonation:

1. Favourable thermodynamics

Since carbonates have a lower energy state than CO₂, essentially, the process should not require any additional input of energy and in fact produces Gibbs free energy. However, as we have seen from the processes and different routes of mineral carbonation above, *additional energy is needed to avoid certain challenges*. Research is still in its early stages to determine the trade-off between cost and energy.

2. Permanence of the storage

Carbon mineralisation is the only sequestration option that is said to keep carbon fixed at carbonates permanently with no risk of any leakages unlike other options where carbon is kept at its gas form (CO₂).

3. Abundant raw materials

The availability of serpentinite and peridotite rock is abundant, Lackner *et al.* (1997) provides a diagram of the world map with highlight of locations rich in these ore bodies. Quantities are very large.



Figure 5-7 Locations of known peridotite or serpentinite ore bodies in the world
(Source: Lackner *et al.* 1997)

Mineral carbonation remains a developing technology, studies presented in the literature today have not provided a thorough assessment of the technology (Mazzotti *et al.* 2005).

In conclusion, mineral carbonation at their current stage of development consumes additional energy and produces additional CO₂. However, it still provides a potential option if the technology is developed further so as to reduce the costs and overcome these challenges.

5.2.2 Industrial uses of carbon dioxide

In this section, methods of utilising CO₂ through industrial uses by either using it directly or as feedstock in chemical processes that produce carbon-based products will be presented.

Carbon dioxide is a valuable industrial gas with many current uses in the production of chemicals, such as, urea, refrigeration systems, inert agent for food packaging, beverages, welding systems, fire extinguishers, water treatment processes, horticulture, precipitated calcium carbonate for the paper industry and other smaller-scale applications (Mazzotti *et al.* 2005).

Although the IPCC report (Mazzotti *et al.* 2005) explains the process by which CO₂ could be utilised as a feedstock for carbon-based products, it however concludes that such efforts are still at the research phase and there are many challenges that delay the development of such technologies. Options available for such utilization of CO₂ are included below.

Carbon

Carbon (C) is the fourth most abundant element in the universe (Darling 2009). Carbon materials can be found in a variety of forms: graphite, diamond, carbon fibers, fullerenes, and carbon nanotubes. The reason why carbon forms many structures is that a carbon atom can easily chemically bond with other atoms (Saito *et al.* 1998).

The word Carbon, *carbo* in latin which means coal, was coined by Antoine L. de Lavoisier in 1789 (Weeks 1956 cited in Bourrat 2000), by the end of the eighteenth century, the two forms of **graphite** and **diamond** were known to be of the same element (Greenwood and Earnshaw 1984 cited in Bourrat 2000) and these were the only known forms of crystalline carbon for some time (Bourrat 2000). In 1985, the **fullerenes** form was discovered (Bourrat 2000). The figure below shows the three known carbon allotropes and their derivatives:

5.2.2.1 Polymorphism of Carbon:

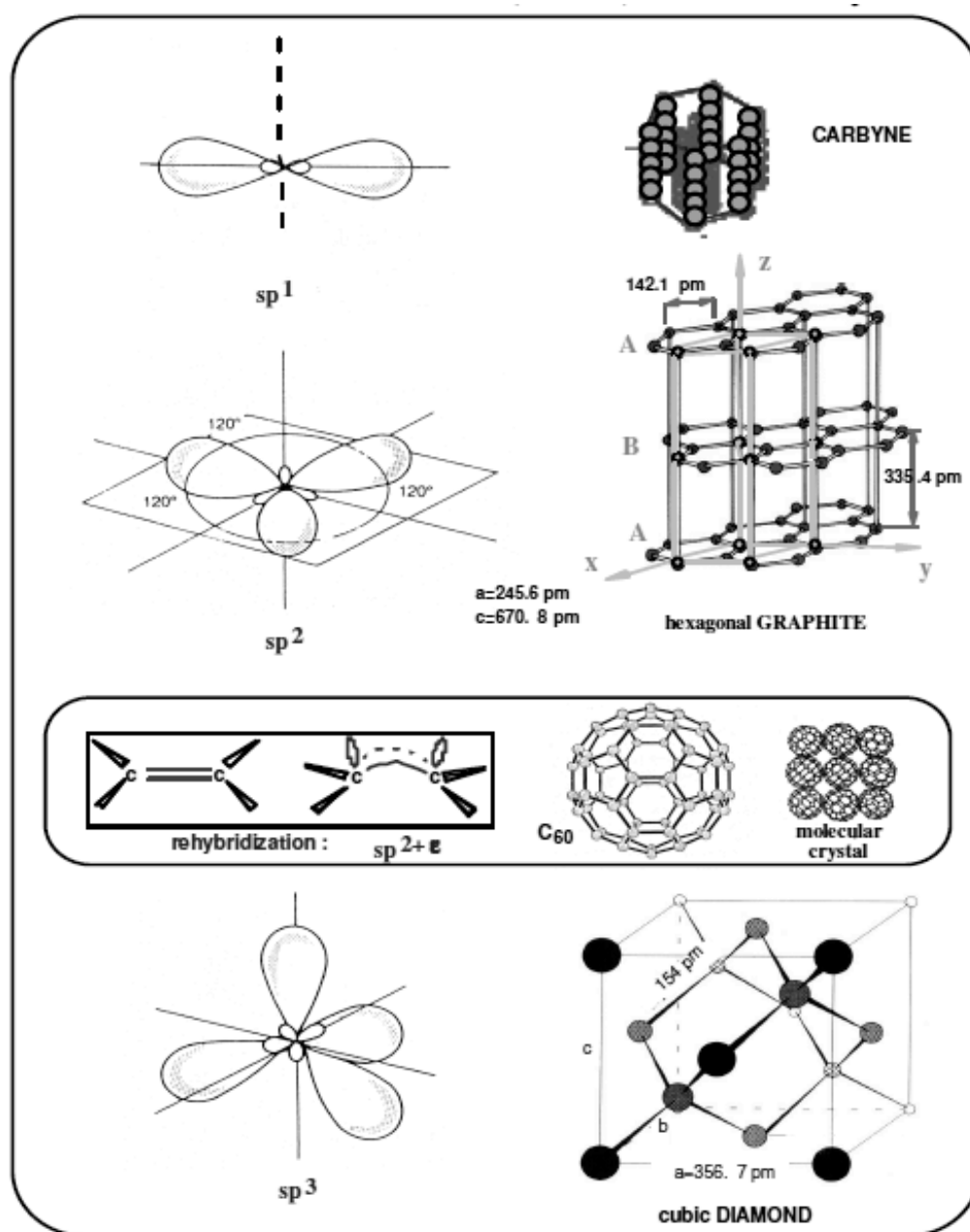


Figure 5-8 Catenation of Carbon (Source: Bourrat 2000)

Carbon's unique polymorphism character enables it to bond to numerous elements including itself, with more than ten allotropic forms (Bourrat 2006).


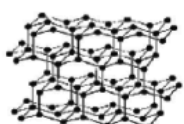
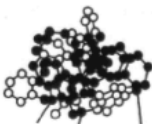
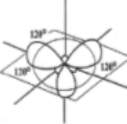
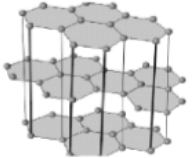





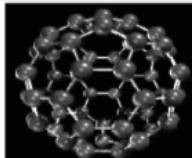

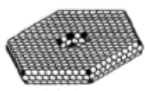


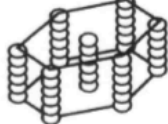

Bonding Hybridization	Allotropes	Derived and Defective Forms
 SP^3	 Cubic diamond	 Diamond-like Carbon
 SP^2	 Hexagonal graphite	<div>     </div>
 $SP^{2+\epsilon}$ rehybridization	 Fullerene	<div>    </div>
 SP^1	 Carbyne	 Nanotubes

Figure 5-9 Carbon Allotropes (Source: Adapted from Bourrat 2000 cited in Mochida 2006)

5.2.2.2 Carbon Materials

5.2.2.2.1 History of Carbon Uses

From the early days and until today, carbon materials are applied in our daily lives. *“Carbons have always been the friendliest of materials. Over several millennia they have generously supported the activities of humankind”* (Marsh 1997). In Pre-1880, carbon was used as **lamp black** (writing), charcoals (gunpowder, medicine, deodorants), **Natural graphite** (writing material). From 1880-1940, carbon uses have evolved to **Activated carbons** (water and air purification), **carbon black** (electrically-conductive plastics, purpose plastics, tires, paints, coatings, electrodes, fuel cells, and inks for printing), **coal coking** (coal-tar pitch), **delayed coking**, **synthetic graphite** and **diamond**. And finally from 1940-today, carbon discoveries led to applications in many industries: **carbon fibers** (PAN, pitch-based, microporous, ultra-light graphite

sporting goods and aircraft brakes), **carbon/resin composites**, **carbon/carbon composites** (aircraft brakes, automobile brakes, rocket nozzles, nose cones and structural materials in the aerospace industry) (Murdie 1997) and **carbon foams** are used to make fire retardant insulation (Marsh 1997, PSU 2009).

The first carbon nanotubes was prepared by Thomas A. Edison to provide a filament for an electric light bulb of an early model (Saito and Dresselhaus 1998), however, Somio Iijima of NEC Corporation first discovered nanotubes in 1991 (Gibson 1999)

Carbon provides useful and unique performances in many fields, such as (Mochida *et al* 2006): electric and heat conductions (conductor and semi-conductor), energy storage (battery anode, super capacitor and gas storage), environmental protection (activated surface), and special materials (mechanical reinforcement, high temperature); Carbon black is used for tyre industry or coke for metallurgical applications

Carbon nanotubes

A carbon nanotube (CNT) in its simplest form can be described as a single-layered seamless graphite rolled into a tube (Jonsson 2007). They are only a few atoms in circumference and are measured in nanometres (billionths of a meter). Possible uses for CNTs: Transistors and diodes, Field emitter for flatpanel displays, Cellular-phone signal amplifier, Ion storage for batteries, and Materials strengthener (Jonsson 2007).

5.3 Solar Energy

The sun is the source of energy in our universe, it is the closest star to Earth. Figure 5-10 represents the sun as the source which other life-essential processes in nature depend upon, such as a warm atmosphere that makes earth a liveable planet, photosynthesis for plants, and the hydrologic cycle. It is also the source which other renewable energy sources depend on, such as wind energy, tidal energy, and hydro energy.

The utilization of solar energy goes back in historic times, when solar heat – now called solar thermal energy – has been used for cooking, heating water and living spaces. Today, modern technological developments provide various ways of capturing solar energy and converting it into usable electricity. The main advantage of solar energy is that the source is reliable, renewable and free, and the process does not produce CO₂ emissions, so it is a sustainable and clean energy used for heating and generating electricity.

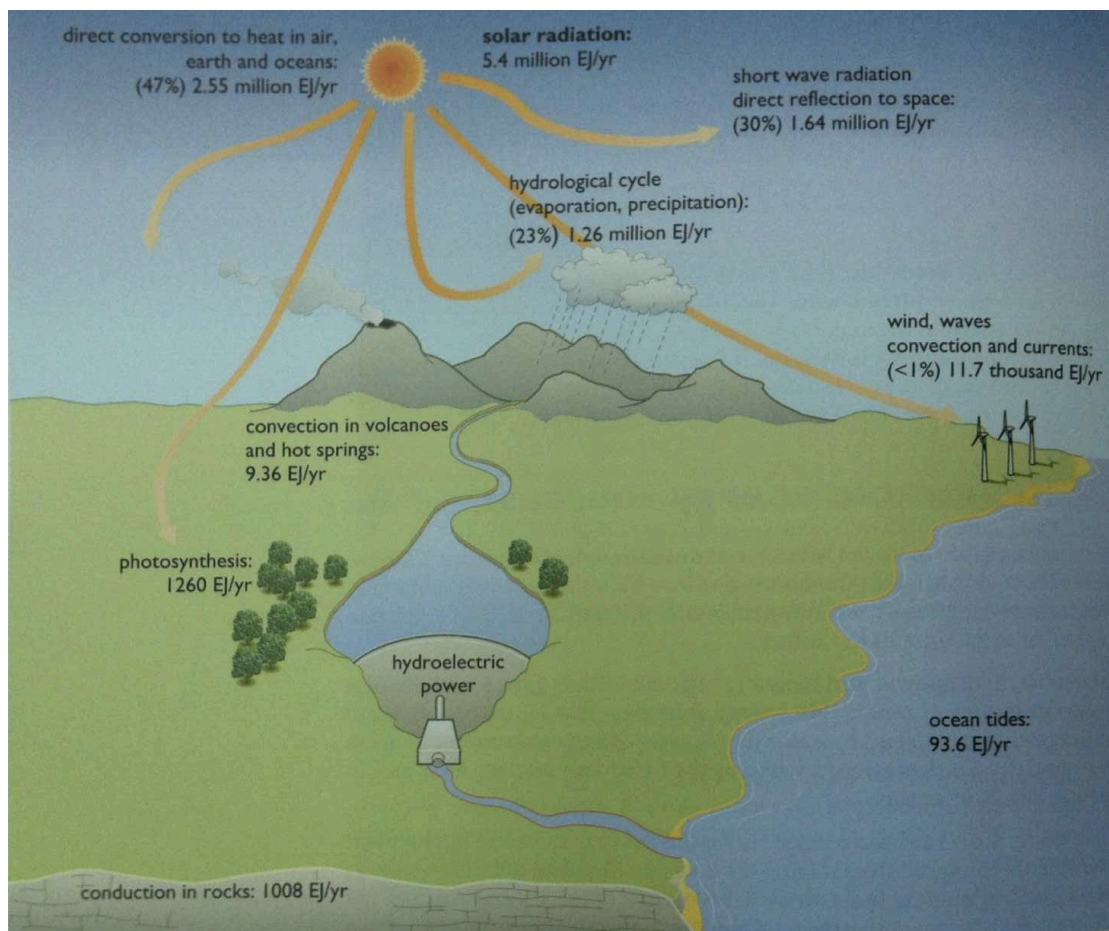


Figure 5-10 The various renewable energy forms depend on the sun (Source: Boyle *et al.* 2003, p. 24)

Small-scale uses of solar energy can be utilised at a rather lower technology. One way of collecting heat is using what is known as a *parabola* or concentrated solar power (CSP), it is a satellite-like bowl/disk made from a reflexive coating that reflects sunlight and collects it into a single spot. Usually a tube of a liquid is placed at the centre, which is heated and is typically used as a water heater for a small house. Another way of harvesting sunlight is the

use of *flat plate*, which composes of three layers, air space (water), black metal and metal transferor, sandwiched in plates of glass. The sun hits the black metal which absorbs heat that is transferred by metal transferor, the heated water could be used for electricity via steam (Encarta Encyclopedia).

Here, an overview on the main modern technologies used to capture solar energy is provided, starting with (5.3.1) solar photovoltaic, followed by (5.3.2) solar thermal energy, and a discussion on the status of the technology, where it is employed in the world and how future trends are predicted.

5.3.1 Solar Photovoltaic

One of the modern converting technologies for capturing solar energy is using solar cells / panels, to be referred to here as solar photovoltaic (Solar PV). Solar PV are made of semiconductor materials, for example, specially-treated silicon crystals, when direct sunlight hits the surface of silicon crystals they force electrons out of orbit forming spaces filled by other silicon atoms – this movement creates a current which can be utilised as electricity (UNEP 2011, Solar VP 2011).

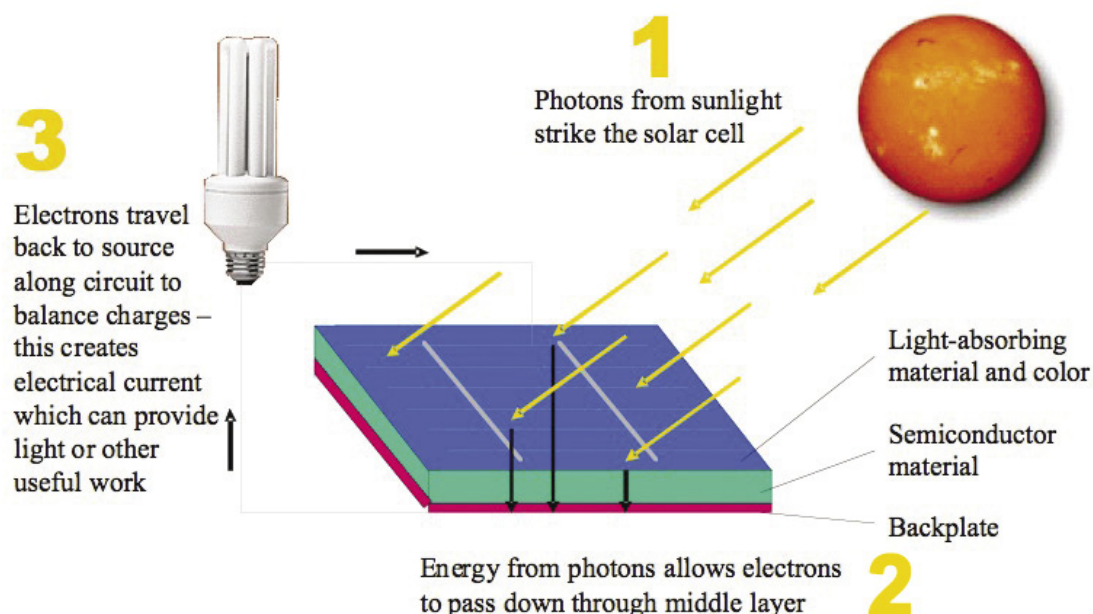


Figure 5-11 How Solar Photovoltaic Works (Source: SECO 2011)

The figure shows a simple process that explains how solar photovoltaic (PV) works. The solar photovoltaic cells consist of three layers, the light-absorbing

material (blue), the semiconductor material (green) and backplate (red) It starts with protons from (direct) sunlight which is received on the surface of a solar panel, it allows electrons to pass through the middle layer, these in turn travel to supply the circuit with electrical current to provide light or other useful form of energy.

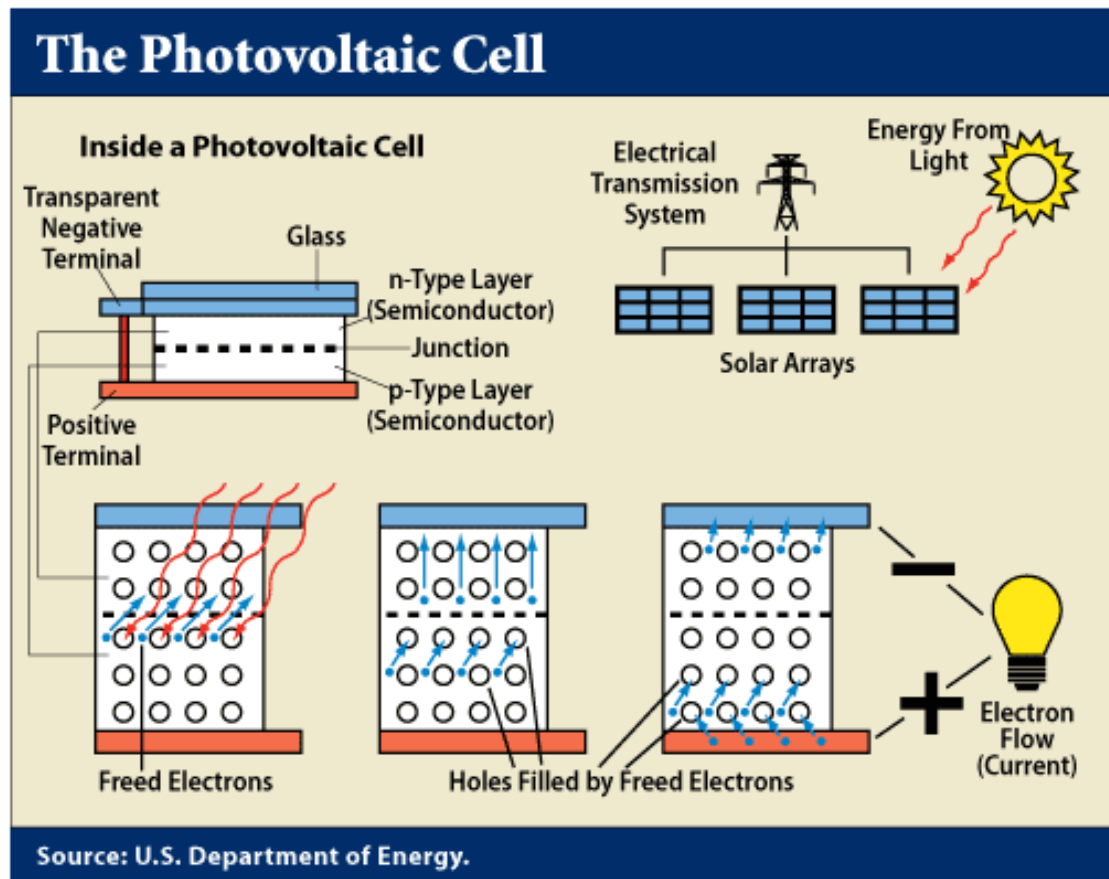


Figure 5-12 The Photovoltaic Cell (Source: Combs 2011)

The figure shows a scheme explaining what happens in a photovoltaic cell. There are two layers made of semiconductor material, a positive terminal with a positive charge and the negative terminal with a negative charge; as the sun hits the surface of the cell, freed electrons makes space which are filled by electrons – the flow current created by electron creates electricity (Combs 2011).

The cost of Solar PV cells is falling, in the past decade, they have fallen steadily as shown in the figure below.

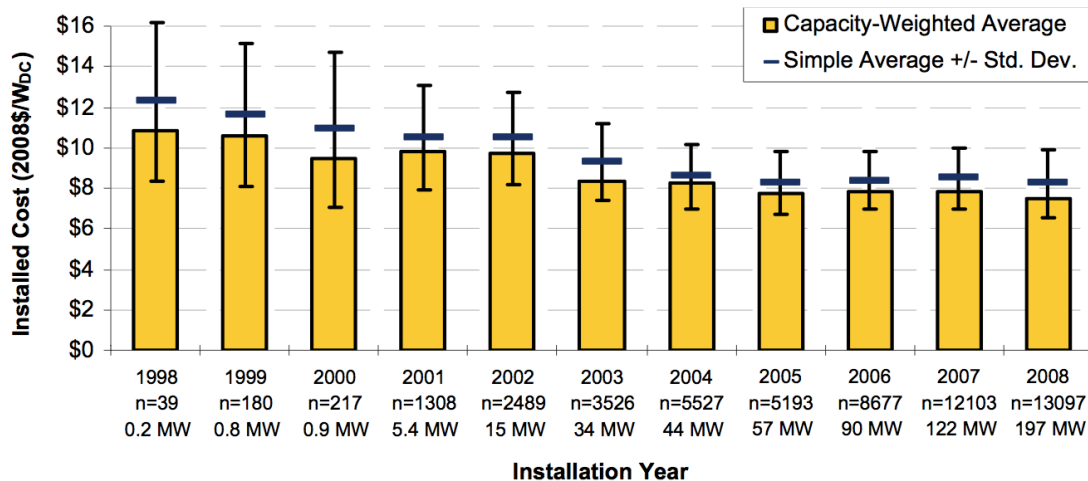


Figure 5-13 Falling Cost of Solar PV between 1998-2008 (Source: Wiser 2009)

Leading countries in cumulative installed capacity is lead by Germany at 9.7 GW, constituting 42.2% share of world total solar energy, followed by Spain at 3.4 GW, constituting 14.0% of world share, then Japan at 2.6 GW, making 11.5% of world share, and then the US at 1.6 GW, making 7.2% of world share (BP 2010).

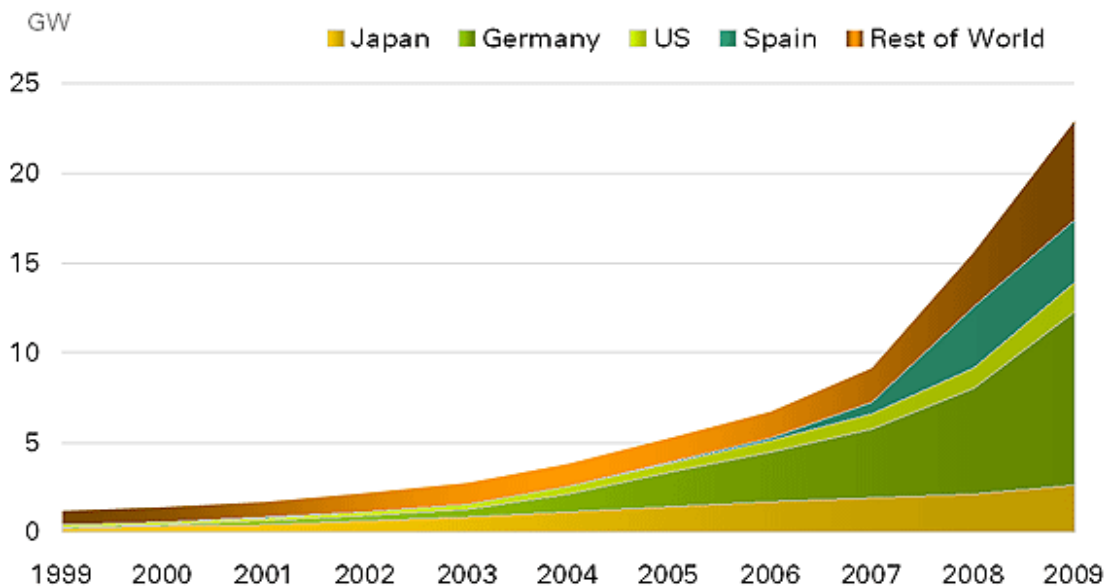


Figure 5-14 Solar PV Capacity (Source: BP 2011)

5.3.2 Solar Thermal

Solar thermal electric energy, it is used to concentrate light from the sun to create heat used to run heat engines. A working fluid is used to be heated,

this can be liquid or gas such as water, oil, salts, air, nitrogen, helium etc., engines include steam engines and gas turbines (Solar-thermal 2008). Leading solar thermal players include Spain and Australia.

The figure below shows a comparison of electricity costs between different types of renewables, solar PV is the highest today (2010) but is expected to fall in 2020 and further in 2035.

Electricity generating costs of renewables in the New Policies Scenario

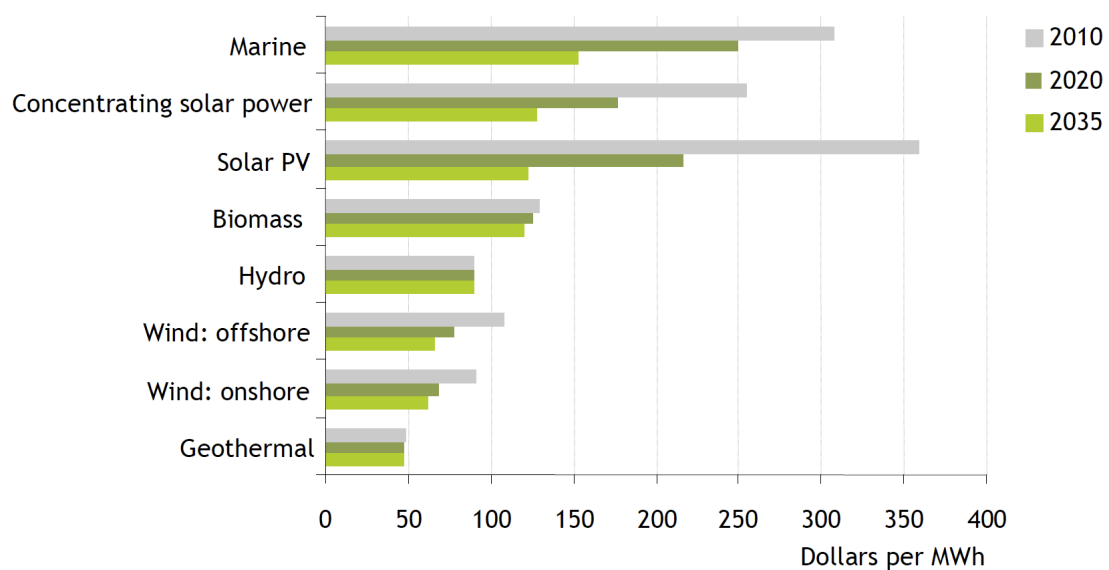


Figure 5-15 Electricity Costs of Renewables (Source: WEO 2010)

Although the technology is advancing and the cost of solar energy is falling and expected to fall further, the current share of solar energy from total global primary energy supply is virtually insignificant. A diagram below shows the shares of energy sources in total global primary energy supply in 2008.

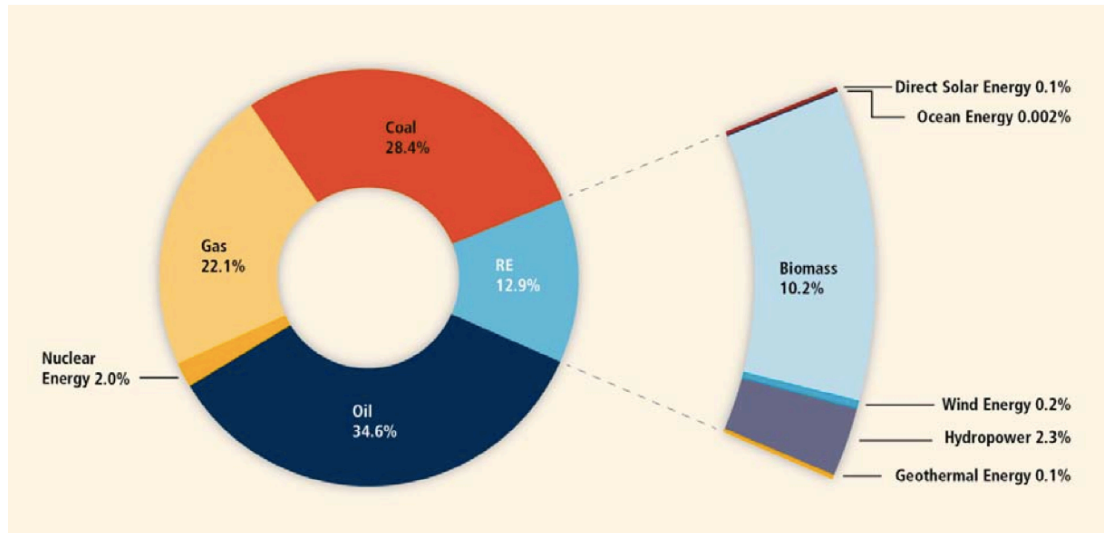


Figure 5-16 Shares of energy sources in total global primary energy supply in 2008 (Source: IPCC 2011)

Renewable energy makes up 12.9% of total global primary energy supply, most of which is biomass (10.2%), solar energy only makes 0.1% of total global primary energy supply. This relatively insignificant amount could reflect the great challenge of this technology to replace fossil fuels completely, but it certainly provides unmatched benefits of reducing carbon dioxide emissions in an economy as well as utilise an abundant solar resource. Therefore, solar energy is a vital ingredient in a larger portfolio of carbon management technologies.

5.4 Conclusion

In this chapter, a portfolio of CM technologies is put together for the case study of Saudi Arabia. Since it is an oil-producing country with massive solar potential, a certain focus was given to carbon management energy technologies that will allow the continued utilisation of fossil fuels, turning it into useful materials, and also solar energy technologies were included to utilise the great solar potential.

6 Transition Pathways to Cleaner Energy for Saudi Arabia

This chapter is the first finding chapter, which uses a quantitative inquiry examining the case study of the energy sector in Saudi Arabia. It presents a projection of energy consumption and CO₂ emissions in the electricity sector for Saudi Arabia up to 2025, with a focus on two carbon management technologies, carbon capture installation and solar photovoltaic generation.

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6 Transition Pathways to Cleaner Energy for Saudi Arabia

Introduction

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6.1.2 Saudi Arabia's Electricity Emission Factor

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6.5 Introducing CCS and Solar PV to the Saudi Arabian Electricity Sector

6.5.1 Data Source

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6.5.3 Introducing Solar to the Saudi Energy Mix

Introduction

This chapter examines the Saudi Arabian electricity sector and illustrates transition paths to cleaner energy generation by applying both CCS technologies and Solar PV technologies to the electricity generation sector. By first providing a brief overview on the Saudi Arabian electricity sector, followed by a summary of the literature review on LCA studies conducted for both CCS and Solar PV. The results are presented after applying these cleaner energy technologies and their CO₂ reduction mechanisms in different scenarios, projecting energy consumption and different CO₂ emissions scenarios for Saudi Arabia for the period 2010 to 2025.

CCS is an end-of-pipe group of technologies that offer promising mitigation solutions for cleaner power generation from fossil fuels, Solar PV is the fastest growing renewable energy technology. Both CCS and Solar PV offer potential advantages to the Kingdom's energy sector in that the former reduces CO₂ emissions while allowing the continuous use of fossil fuels and the latter utilises the rich resource of direct sunlight across the vast lands of Saudi Arabia.

In this study, using LCA, a model that offers a holistic approach to decision-makers, the inherent advantages of applying CCS and Solar PV to the Saudi electricity sector is projected. Recent studies, as shall be seen, show variant results of reduction in life cycle greenhouse gases (GHG), especially CO₂ from applying CCS and Solar PV.

6.1 The Saudi Arabian Electricity Sector

It has been seen in Chapter 3 how CR has heavily fuelled power generation in the Kingdom of Saudi Arabia ever since the inception of its oil industry. NG is increasingly becoming a source for power generation in the Kingdom since the 1970s, after it has been flared in the air for years, not only wasting an invaluable natural resource but also contributing to a growing cumulative CO₂ emission level. The Kingdom today still burns CR for its power generation, this is due to the easy availability of CR (world's largest oil reserves) relative to

that of NG (world's fifth largest gas reserve) and mostly due to the ever-increasing demands of its growing population and economic development.

The burning of CR for power generation, although today is slightly less (48%) than NG is likely to continue in the foreseen future and is expected to increase, as we will discuss later. Therefore, the technologies of CCS and Solar PV, as we shall see in this chapter, present an unrivalled opportunity for the Kingdom to both sustain its oil-rich economy, oil-based power generation, as well as contribute in its transition to sustainability by addressing its carbon emission problem. This will also provide a 'bridging' platform towards a more sustainable future for its energy sector—as discussed in previous chapters.

6.1.1 Electricity Forecast:

The following forecasts are used in the current study; these forecasts have been developed by KFUPM (2006a), as will be explained in detail later, as part of the Long Term Generation Planning for the Saudi Electricity Sector study. Population, and population forecast, in Saudi Arabia is shown below between 1986-2023, this is according to the Ministry of Planning and Economy (KFUPM 2006a).

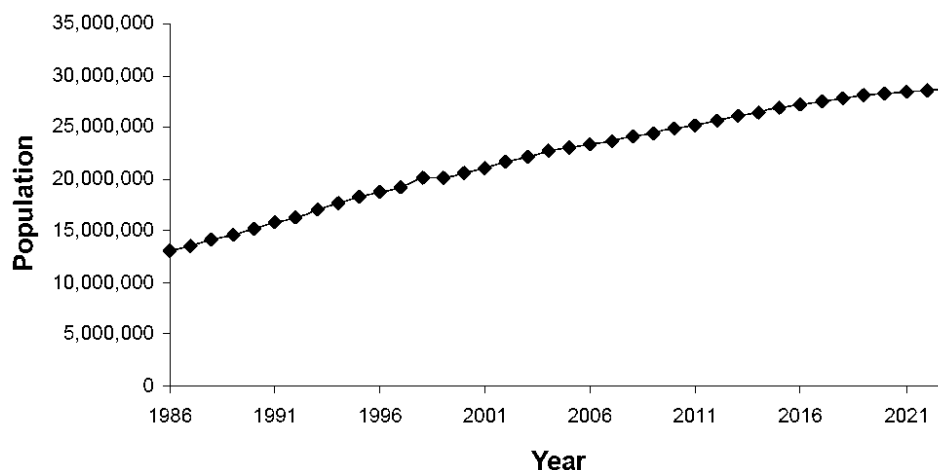


Figure 6-1 Saudi Arabia's population and population forecast, 1986-2023 (Source: Ministry of Planning cited in KFUPM 2006a, p. 6)

Figure 6-1 shows the Saudi population figures and forecasts between 1986 and up to 2023 developed by the ministry of planning (MEP), the figures of the population is shown below in Table 6-1. The average annual growth rate of

the total population is 0.87%, this includes a growth in Saudi population of 2.25% and a negative growth of Non-Saudis at -1.38%.

Table 6-1 Population (Source: Central Department of Statistics and Ministry of Economy and Planning estimates, MEP 2006)

	Population (Million)					Average annual growth rate (%) 2004–2024
	2004	2009	2014	2019	2024	
Total population	22.67	24.39	26.52	28.26	29.86	0.87
Saudis	16.53	18.57	20.86	23.32	25.81	2.25
Non-Saudis	6.14	5.82*	5.66	4.94	4.05	-1.38

* MEP estimates which take into consideration decrease in foreign-labor force due to Saudization.

Figure 6-2 shows the historical and forecasted gross domestic product (GDP), and figure 6-3 shows the historical and forecasted growth per capita, as presented by the report (KFUPM 2006a), which used the Ministry of Economy and Planning (MEP) data, and from the graph shown the growth from 2005 is an exponential growth, which the report argues may be difficult to achieve and therefore, three growth cases have been developed, in the next figure 6-4:

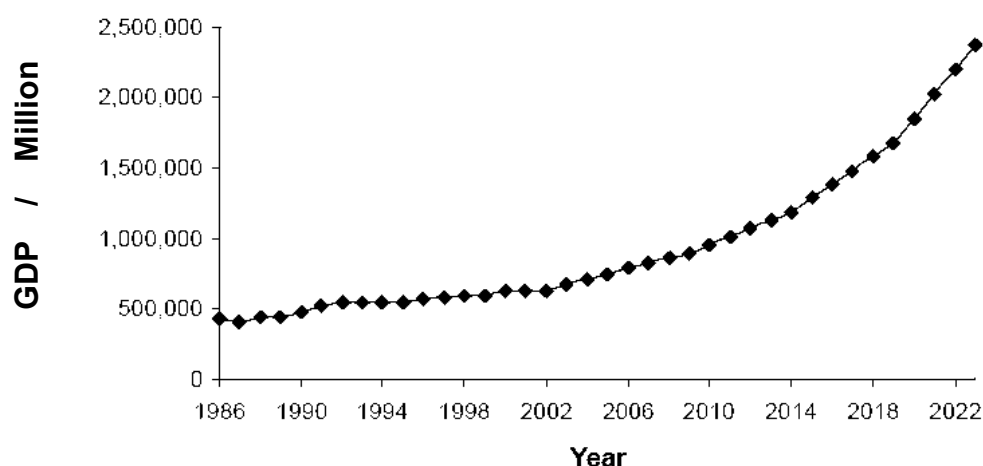


Figure 6-2 Saudi Arabia's GDP and GDP Forecast for the period 1986-2023 (Source: Ministry of Planning cited in KFUPM 2006a, p. 5)

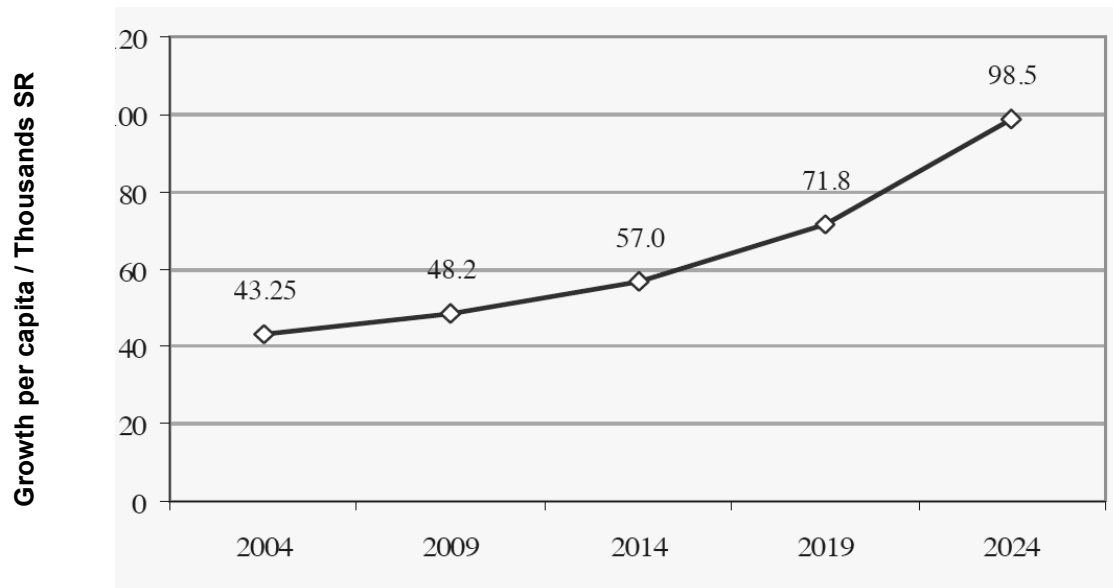


Figure 6-3 Saudi Arabia's Growth per capita Income at 1999 constant prices (Source: Macroeconomic Projections, Ministry of Economy and Planning, in MEP 2005:, p. 10)

The report (KFUPM 2006a) used the Econometric Regression Analysis method to generate the load forecasting for Saudi Arabia, this method as well as the Application Saturation Methods and End-Use Energy Methods are widely used for forecasting load energy (KFUPM 2006a). Using historical annual energy, population and gross domestic product (GDP), the KFUPM team determined customer elasticities and assumed that they will not change during the period of the study (2008-2023) to produce a forecast for sold energy. For calculating the load forecast for energy, the report used historical and forecasted data for population and GDP from MEP, Figure 6-1, 6-2, and 6-3, and used energy data from the Saudi Electricity Company.

Three growth rates for the Kingdom GDP has been proposed by the study team at KFUPM, these are presented below in Figure 6-4. The MEP GDP figures, Figure 6-2, show an exponential growth from year 2005, these now make the High Growth Case, the Most Likely Growth Case is maintaining the GDP growth from year 2004 onwards, and the Low Growth Case was obtained by reducing the Most Likely Growth Case GDP by 20% each year. These three growth cases will be used in the current study, *see Appendix for business-as-usual high and low growth cases.*

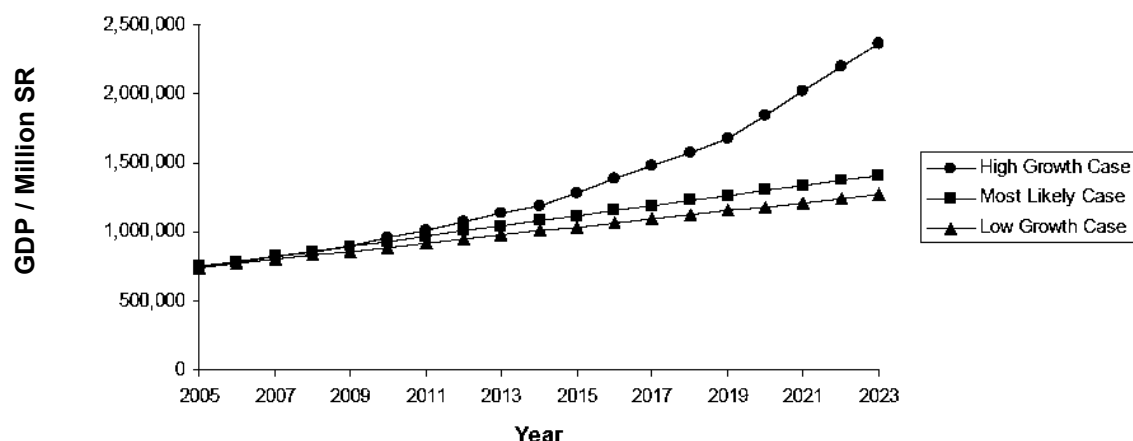


Figure 6-4 Saudi Arabia's GDP for Three Growth Cases (Source: KFUPM 2006a)

6.1.2 Saudi Arabia's Electricity Emission Factor

Table 6-2 below shows Saudi Arabia's total CO₂ emissions, 2006 emphasised (in thousands metric tonnes) = 381,564 tCO₂, if it is compared with the Table 6-3 for Foreign Electricity Emission Factors (1999-2002), Saudi Arabia's electricity sector CO₂ emissions, using 2008 electricity demands = **162,193,872 tCO₂**. Hence, more than 50% of CO₂ emissions come from non-electricity generation sources, namely, the transportation and energy (oil and gas) sectors.

Table 6-2 Saudi Arabia's total carbon dioxide emissions in Mt CO₂ (Source: EIA 2010b)

The Kingdom of Saudi Arabia's Total Carbon Dioxide Emissions					
Year	2004	2005	2006	2007	2008
Carbon Dioxide Emissions / MtCO ₂	388.763	405.540	406.193	433.931	466.048

From the US Department of Energy, **Foreign Electricity Emission Factors, 1999-2002**, Saudi Arabia's figure include:

Table 6-3 Foreign Electricity Emission Factors, Saudi Arabia, 1999-2002 (Source: EIA 2007)

Region Country	Emission Inventory			Emission Reductions	
	Carbon Dioxide / t/MWh	Methane / kg/MWh	Nitrous oxide / kg/MWh	Avoided emissions / t CO ₂ -e/MWh	Indirect emissions / t CO ₂ -e/MWh
Saudi Arabia	0.816	0.02678	0.00487	0.818	0.873

The Kingdom's electricity emission factor from table 6-3 above is from the International Energy Statistics (EIA 2007), calculated based on average emissions intensity of total electricity sector generation, including its electricity mix, transmission and distribution losses in the electricity grid between 1999-2002.

To compare the US EIA emission factor for Saudi Arabia in Table 6-2 with that of Table 6-3 below by Alnatheer (2002) cited in Alnatheer *et al.* (2006), the column before last in Table 6-4 presents the CO₂ assumed emission factor in grams per gigajoule of fuel input (g/GJ fuel input), **72,726 g/GJ** for crude oil (CR) was selected, which is the middle figure between 72,726 g/GJ for heavy fuel oil (HFO), 50,349 g/GJ for natural gas (NG) and 73,882 g/GJ for diesel (D), at an assumed efficiency rate of 40%, the emission factor is **0.647 tCO₂/MWh²⁷**.

Table 6-4 Power plant air pollutant emission factors used (Source: Alnatheer 2002 in Alnatheer 2007)

Generator type	Region	Fuel	Assumed emission factors (gm/GJ fuel input)						
			NO _x	SO _x	CO	PM-10	VOC	CO ₂	CH ₄
Combined cycle	North	LT Crude	123.1	1857	12.3	5.9	3.4	72,726	0.8
Combust. turbine (53 MW)	North	LT Crude	123.1	1857	12.3	5.9	3.4	72,726	0.8
Combust. turbine (28 MW)	North	LT Crude	123.1	1857	12.3	5.9	3.4	72,726	0.8
Combined cycle	Central	Crude	123.1	1857	12.3	5.9	3.4	72,726	0.8
Combined cycle	Central	Nat. Gas	95.8	1.4	18.4	0	1.6	50,349	0.5
Gas turbine	Central	Crude	123.1	1857	12.3	5.9	3.4	72,726	0.8
Combined cycle	East	Nat. Gas	95.8	1.4	18.4	0	1.6	50,349	0.5
Steam turbine	East	Nat. Gas	95.8	1.4	18.4	0	1.6	50,349	0.5
Gas turbine	East	Nat. Gas	95.8	1.4	18.4	0	1.6	50,349	0.5
Combined cycle	South	Diesel	219.8	181.6	49.9	8.1	15.5	73,882	0.8
Steam turbine	South	Diesel	77.9	186.4	16.2	3.2	0.6	73,882	0.8
Gas turbine	South	Diesel	219.8	181.6	49.9	8.1	15.5	73,882	0.8
Steam	West	HFO	123.1	1857	12.3	5.9	3.4	72,726	0.8
Combined cycle	West	Crude	123.1	1857	12.3	5.9	3.4	72,726	0.8
GAS turbine	West	Crude	123.1	1857	12.3	5.9	3.4	72,726	0.8

The result shows that the assumed emission factor by Alnatheer (2002, 2007) of **0.647 tCO₂/MWh** is lower than that of **0.816 tCO₂/MWh** from US DoE (EIA

²⁷ 72,276 g/GJ = 0.072 t/GJ = 0.000072 t/MJ = 3.6 x 0.072 t/MWh = 0.259 t/MWh = 0.647 t/MWh at 0.4 efficiency.

2002). In this study, for the sake of caution I shall use the latter from US EIA (2007).

Having clarified the Saudi Arabian figures to be used in this study, in the following section, a brief explanation on LCA, the method followed in the studies on cleaner energy technologies used in this current study will be provided.

6.2 Life Cycle Assessment Method

LCA is an important method for measuring the overall environmental footprint performance of a particular energy technology. It has been standardized by the International Standards Organisation (ISO) in the ISO-1404 series (ISO 2006) and has been used extensively in the literature for projecting the life cycle energy and environmental impacts of cleaner energy technologies. Especially with the increasing interest in environmental sustainability, LCA is becoming an increasingly essential method for decision-makers and academics alike.

Wiedmann and Minx (2007) suggest that there are two methodology approaches to calculating carbon footprints, bottom-up and top-down. Bottom-up, they explain, is based on process analysis, whereas, top-down deals with environmental input/output analysis. Both approaches *inform* a full LCA.

Some definitions that clarify the role of an LCA:

- | | |
|--|--|
| PSI (2009): | “Life Cycle Assessment (LCA) deals with all the industrial activities involved in the fabrication of a product or the delivery of a service as well as the exchanges between such activities and the environment. Life Cycle Inventory assessment (LCI) accounts for all material and energy flows occurring during the three phases of production operation and decommissioning over the life of every activity.” |
| EUROPA-Site (2009): | “An LCA of a product includes all the production processes and services associated with the product through its life cycle from the extraction of raw materials through production of the materials which are used in the manufacture of the product over the use of the product to its recycling and/or ultimate disposal of some of its constituents. Such a complete life cycle is also often named ‘cradle to grave’ “ |
| Consoli et al. 1993 cited in Hu et al. (2008): | “Life cycle assessment (LCA) is a method to define and reduce the environmental burdens from a product process or activity by identifying and quantifying energy and materials usage and waste discharges assessing the impacts of the wastes on the environment and evaluating opportunities for environmental improvements over the whole life cycle” |

Alternative Methods

There are a number of environmental assessment options available for CCS as well as other cleaner energy options. Some alternative analytical tools include:

- Green Foresight
- Environmental Impact Assessment/Milieu Effect Rapportage
- Multi criteria analysis
- Risk analysis
- Cost benefit analysis
- Integrated assessment
- Sustainability impact assessment

According to the United Nations Framework Convention for Climate Change (UNFCCC) Resource Guide, there are four main tools of energy-sector GHG mitigation assessment:

1. The Energy and Power Evaluation Programme (ENPEP), developed by the Argonne National Laboratory and the International Atomic Energy Agency (IAEA);
2. The Long-range Energy Alternatives Planning system (LEAP), developed by the Stockholm Environment Institute;
3. The Market Allocation Model (MARKAL) and its successor TIMES (The Integrated MARKAL EFOM system), developed by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA);
4. The Renewable Energy and Energy-efficient Technologies Screening system (RETScreen), developed by Natural Resources Canada.

Other popular energy modelling tools, include:

- HYSYS: process modelling software
- GEM: Global Energy Modelling
- ETA: Energy Technology Assessment
- BESOM: Brookhaven Energy System Optimization Model

Studies on cleaner energy technologies, namely CCS and Solar PV, using LCA as a method serves the purpose of this study, which is to examine the

Saudi electricity sector and present illustrative forecast and show the inherent advantages of applying the technologies of CCS and Solar PV to the electricity sector. Such forecasts will offer decision-makers and policymakers the necessary options available to reduce carbon emissions with the minimal expensive changes to the infrastructure of producing and using energy in the Kingdom. In the next section, a summary of the literature review on LCA studies of power generation with and without CCS, is presented, followed by a literature review on LCA studies on Solar PV power generation.

6.3 LCA Studies on Power Generation with the application of Carbon Capture and Storage Technologies

There is a growing number of LCA studies on power generation with and without CCS, as well as other cleaner energy options, for both LCA studies on CCS and Solar PV, the literature published in the past decade between 2000-2010 only, has been reviewed. Weisser (2007) argues that LCA has evolved and improved over time and has therefore generated more accurate results, in addition, regulation and efficiency improvements changed the conditions of emissions as well as energy results, and finally, 'technology experience curves' improves the overall performance of technologies.

Table 6-5 numerates studies that have been *recently* published that analysed the technologies of CCS using an LCA approach, and their potential for reducing life cycle GHG, and/or CO₂ emissions.

Table 6-5 Literature Review for LCA Studies on Fossil Fuel Power Generation with CCS and its environmental impacts and EOR from CCS systems

Study	Fuel		Capture			Transport		Storage				LCA method				Emissions		
	NG	C	PoC	PrC	Oxy	P	S	G	ER	O	A	MEB	FG	F	H	CO ₂	GHG	Ot
1	✓		✓			✓					✓				✓	✓	✓	✓
2		✓	✓											✓		✓	✓	✓
3		✓	✓			✓		✓						✓		✓	✓	✓
4	✓	✓	✓	✓	✓	✓		✓						✓		✓	✓	✓
5	✓		✓						✓						✓			
6	✓	✓	✓	✓	✓	✓		✓					✓			✓	✓	✓
7		✓	✓											✓		✓	✓	✓
8	✓	✓	✓	✓	✓									✓		✓	✓	
9		✓	✓									✓	✓			✓		
10		✓	✓			✓		✓						✓		✓	✓	
11		✓	✓			✓	✓	✓	✓	✓				✓		✓	✓	✓
12		✓							✓					✓		✓		✓
13									✓				✓			✓	✓	
14									✓				✓			✓		
15	✓	✓	✓	✓	✓	✓		✓			✓			✓			✓	✓
16									✓					✓		✓		
17	✓	✓	✓	✓										✓		✓	✓	✓
18		✓			✓	✓			✓					✓			✓	✓
19	✓		✓			✓	✓	✓						✓		✓	✓	✓
20	✓	✓	✓	✓										✓		✓	✓	✓

Key

Fuel		Capture		Transport		Storage		LCA method		Emissions	
NG	Natural Gas	PoC	Post Combustion	P	Pipeline	G	Geological	MEB	Mass Energy Balance	CO ₂	Carbon dioxide
C	Coal	PrC	Pre Combustion	S	Shipping	ER	Enhanced recovery	FG	Foreground LCA	GHG	Greenhouse Gas
		Oxy	Oxyfuel			O	Ocean	F	Full LCA	Ot	Other
						A	Aquifer	H	Hybrid LCA		

References

Study	Reference
1	Singh <i>et al.</i> (2010).
2	Korre, <i>et al.</i> (2010).
3	Pehnt, and Henkel (2009).
4	Odeh and Cockerill (2008).
5	Hertwich, E. <i>et al.</i> (2008).
6	Viebahn <i>et al.</i> (2007)
7	Benetto, E., <i>et al.</i> (2004).
8	Lombardi (2003)
9	Rao and Rubin (2002)
10	Koornneef, J., <i>et al.</i> (2008).

11	Khoo and Tan (2006a)
12	Khoo and Tan (2006b)
13	Aycaguer <i>et al.</i> (2001)
14	Suebsiri <i>et al.</i> (2006)
15	Bauer, C., and Thomas Heck, (2009).
16	Jarmillo, P., W. <i>et al.</i> (2009).
17	Spath and Mann (2004)
18	Pehnt and Henkel (2009)
19	Modahl <i>et al.</i> (2009)
20	IEA GHG (2006)

All references included in Table 6-5 have conducted LCA studies that show a ‘cradle-to-grave’ analysis of applying CCS technologies, from fuel extraction and processing to decommission of power plants. As we will see next, this step-by-step system offers a holistic approach to assessing technologies. Examples of how such an LCA study has been conducted will be discussed.

Other related studies that were not included, in Table 6-5, assessed the technologies of CCS in fossil fuel power generation, but without using an LCA model (for example, Bistline and Rai 2010, Linder *et al.* 2009, Horssen *et al.* 2009, Weisser 2007, Katzer 2007), also some included hydrogen in the production of electricity (such as Doctor *et al.* 2001, Damen *et al.* 2006, Bouvart, and Prieur, 2009). These studies still offer important findings similar to the ones that employed a full LCA. The majority of findings concluded that the application of CCS technologies on power plants reduce life-cycle carbon emissions but *generally* show a worse-off case for other indicators, such as acidification, eutrophication and other toxicity indicators, (see Table 6-9).

Today there is no commercial CCS-installed power plants in operation. Therefore, the majority of these LCA studies (Table 6-5) generate their results based on hypothetical projects (for example Odeh and Cockerill 2008; and Suebsiri *et al.* 2009), with some using existing pilot projects (Viebahn *et al.* 2007, Hertwich *et al.* 2008).

Figure 6-5 below shows the system boundaries of LCA power generation with CCS. It encompasses all the processes and products involved.

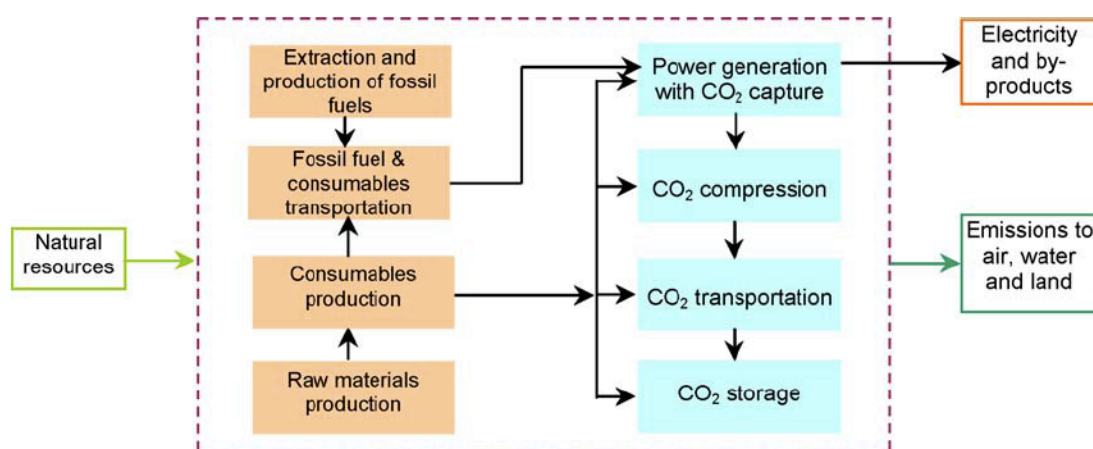


Figure 6-5 System boundaries of LCA in power generation with CCS (Source: Korre *et al.* 2010)

Figure 6-6 below shows an illustration of a CCS-installed system to a gas-power plant for the future Tjeldbergodden gas power plant in Norway of a project led by Statoil in 2006 (Modahl *et al.* 2009).

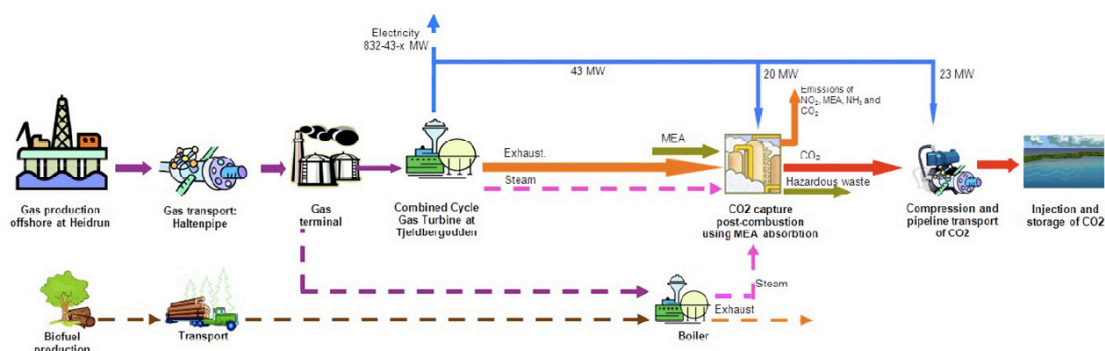


Figure 6-6 Simplified flow chart of a gas power plant with CCS (Source: Modahl *et al.* 2009)

Next, in Figure 6-7, an example of LCA boundaries is provided from Odeh and Cockerill (2007). The LCA study takes into account all the energy, raw materials, and emissions used for all products and processes involved, including: power plant construction, power plant operation and maintenance, upstream processes (fuel production, cleaning and transport), other upstream processes (material extraction and transport), waste disposal (landfilling), waste disposal (recycling), and decommissioning of power plants. Energy,

materials, and emissions have also been recorded for each of the products and processes as shown, indicated by colour codes: black for raw material, red for energy, and blue for emissions.

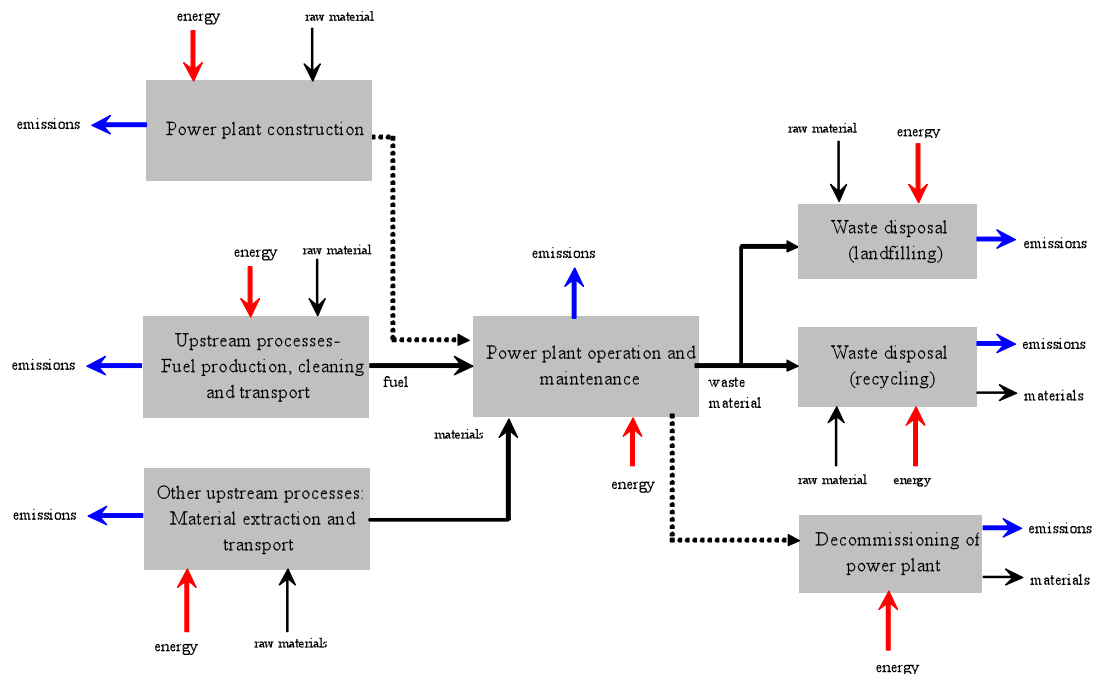


Figure 6-7 Life Cycle Boundaries (Source: Odeh and Cockerill 2007)

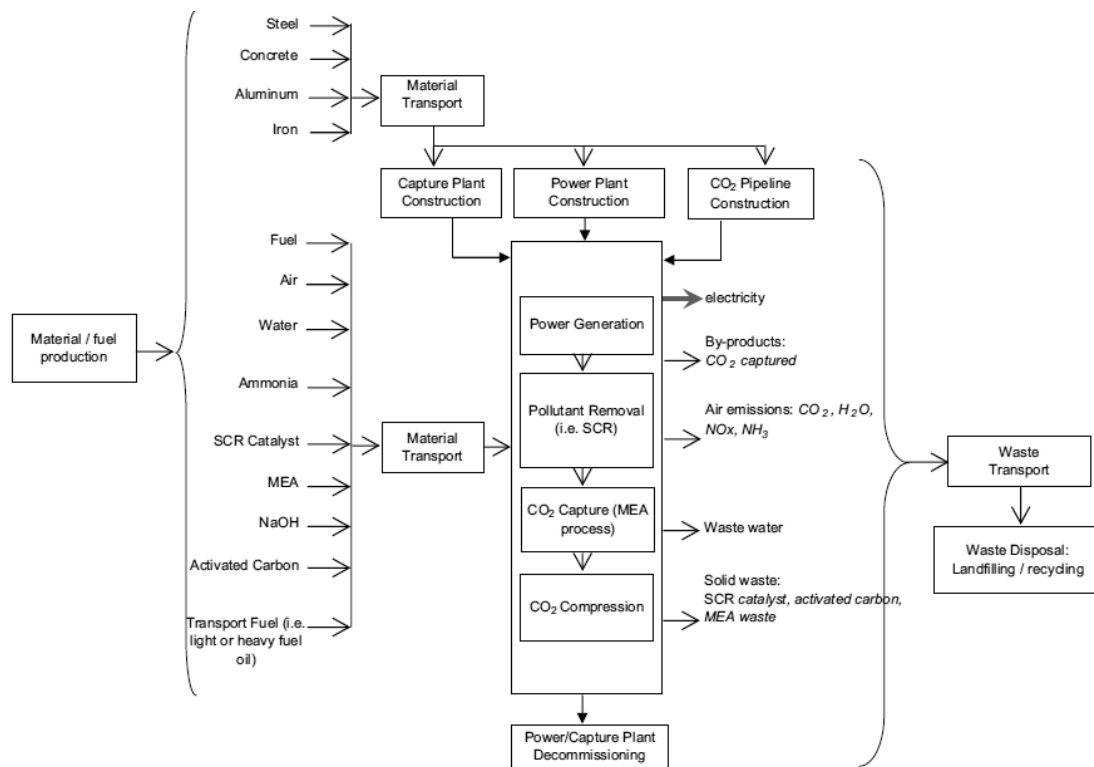


Figure 6-8 Life Cycle Boundaries for NGCC power plant with CCS (Source: Odeh and Cockerill 2008)

Figure 6-8 above provides an example of the input/output balance of energy, materials and emissions from a full LCA study on a Natural Gas Combined Cycle (NGCC) power plant with CCS, as part of the LCA study conducted by Odeh and Cockerill (2008). Full account consists of materials as input, such as steel, concrete, aluminum and iron for the Material Transport of the CCS system (Construction of Capture Plant, Power Plant and CO₂ Pipeline). Other inputs for Material Transport include: fuel, air, water, ammonia, Selective Catalytic Reduction (CSR), MEA, NaOH, Activated Carbon and Transport fuel (light or heavy fuel oil). Power plant process includes: power generation, pollution removal (SCR), CO₂ capture (MEA process), CO₂ compression, and finally Power/Capture Plant Decommissioning. Output consists of the by-products of electricity, including that of power generation (such as CO₂ captured, Gypsu, ash), air emissions (CO₂, H₂O, SO_x, NO_x, NH₃, HCl, particulates), waste water, and solid waste (catalyst, gasifier slag). Finally, the Waste Transport including Waste Disposal (landfilling / recycling).

According to a study by Viebahn et al. (2007) data for fossil fuel-fired power plants to be installed in 2020 in Germany, a comparison between two fossil fuel fired power plants in Germany, including four fuel types, pulverised hard coal, integrated gasification combined cycle (IGCC) hard coal, pulverised lignite, and natural gas combined cycle (NGCC). The power plants with CO₂ capture showed a general decrease of efficiency between 8-12%, and an increase in operating cost by about 40%.

The New Energy Externalities Development for Sustainability (NEEDS) project under the European Commission (Bauer and Heck 2009) published an LCA study to support the development of a European energy strategy up to year 2050. The study provides an LCA on selected fossil fuel fired power plants, *coal and natural gas power technologies*, with and without CCS; The worked LCA presents three different scenarios for years 2005, 2025 and 2050. They analyze the three technology paths for CO₂ capture - pre-combustion, post-combustion and oxyfuel combustion – and also model the Transport for CO₂ using pipeline as well as the storage of CO₂ in geological formation in saline aquifers and depleted gas reservoirs. The reported results show a significant reduction in GHG emissions, taking an example of the base case of NGCC, the figures for GHG emissions are as follows:

Table 6-6 Results of installing CCS for Natural Gas systems impact on GHG Emissions (source: Bauer and Heck 2009)

Realistic-optimistic scenario	With CCS / g (CO ₂ -equivalent)/kWh	Without CCS / g (CO ₂ -equivalent)/kWh
2005	-	400
2025	99	375
2050	95	350

The figures in Table 6-6 show total CO₂ emissions in grams per kilowatt-hour, g/kWh, for the life cycle inventory in natural gas fired power plant systems with and without CCS, the LCA covers: fuel extraction and processing, power plant construction and dismantling, power plant operation (including carbon capture and compression), and carbon transport and storage, for the realistic-optimistic scenario. Application of CCS leads to substantial reduction in life cycle GHG for the year 2025 and 2050 by 73.6% and 72.8%, respectively.

Table 6-7 Summary of Global Warming Potential and Energy Balance for Fossil Power Systems
(Source: Spath and Mann 2004)

No.	System	Case	Net GWP (g CO ₂ eq./kWh)	Fossil energy consumption (MJ/kWh)	Changes in:	
					GWP	Energy use
1	Coal-fired reference	1	847	12.5	N/A	N/A
2	Coal-fired w/CO ₂ seq	1a	247	14.6	-71%	16%
3	NGCC - reference	2	499	8.4	-41%	-33%
4	NGCC w/CO ₂ seq	2a	245	9.7	-71%	-22%

Similarly, Table 6-7 above shows another example of results from the US DOE LCA study on Coal and Natural Gas power plants, the original study includes biomass which has been excluded here. Number 2 and 4 show the scenarios with the application of CCS, reducing Global Warming Potential (GWP)²⁸ at 71% for both Coal and Natural Gas. Energy use is 16% in Coal and of -22% Natural Gas systems. The latter is due to its fuelling of the excess capacity of energy use required by the CO₂ sequestration process, this is explained as follows: “*For the NGCC system, the upstream processes are responsible for a considerable amount of GHG emissions and energy consumption, accounting for 25% of the total GHG emissions and 21% of the total fossil energy consumption*” (Spath and Mann 2004, p. 8).

The results of the LCA from the future Tjeldbergodden case study in Norway (Modahl *et al.* 2009) are summarized in Figure 6-9 below, showing a GWP reduction in all CCS scenarios when compared to the Reference scenario (without CCS). However, all scenarios showed a worse-off performance in other environmental indicators, such as: acidification potential, eutrophication potential, photochemical ozone creation potential, and cumulative energy demand. These results are also commonly reported by other LCA studies on

²⁸ GWP is a measure of how much the masses of GHGs contribute to global warming. A high GHG correlates to high infrared absorption and long atmospheric lifetime.

CCS.

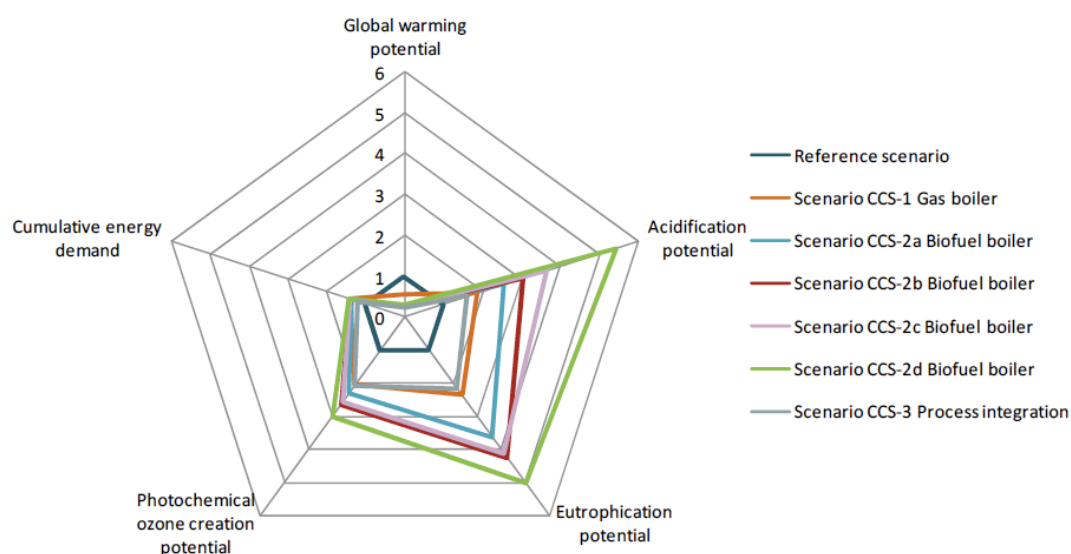


Figure 6-9 Relative Impact of CCS Scenarios in relation to the Reference Scenario (Source: Modahl *et al.* 2009)

Weisser (2007) provides a guide that compares different energy systems, including fossil fuel generation systems, nuclear and renewable energy technologies (RET) and carbon capture and storage systems. He concludes that RETs provides the lowest GWP amongst all energy systems, but CCS systems installed on fossil fuel generation systems provide the lowest GWP when compared to that with no CCS systems installed. Like the IPCC Special Report on CCS (IPCC 2005) Weisser reports CCS GWP reduction by 80-90% and argue lower variations (like Spath and Mann 2004) are due to “two assumptions, substantial down-stream emissions from energy chains that cannot be captured by CCS systems, and the extra energy capacity use by adding a natural gas combined cycle system, which makes $\frac{1}{2}$ and $\frac{1}{3}$ of the life cycle emissions” (Weisser 2007, p.1551).

Horssen *et al.* (2009, p. 5), in their report for the Netherland Environmental Assessment Agency, state that: “Changes in the level of NEC²⁹ emissions are

²⁹ The National Emission Ceiling (NEC) directive (2001/81/EC) the European Parliament and the Council on National Emission Ceilings for certain pollutants sets upper limits for each Member State for the total emissions in 2010 on four pollutants: sulphur oxide (SO₂), nitrogen oxide (NO_x), volatile organic compounds (VOCs) and ammonia (NH₃).

not a bottleneck for CCS implementation... mitigation measures can be applied using current available technology without significantly changing the economic feasibility of the options". The impact category of interest in this study is Global Warming and specifically that of CO₂. Table 6-8 below shows the merged results of selective studies for the use for the Saudi Arabian case.

Table 6-8 Summary of selected cases summarizing life cycle environmental impacts for CCS technologies

Case	Power Plant	Fuel	Capacity	Carbon Capture	Transport	Carbon Storage	Reduction rate
Hertwich <i>et al.</i> 2008	CC	NG	832 MW	Post-combustion capture (amine as a solvent)			80% (GWP)
Odeh and Cockerill, 2008	CC IGCC	NG C	500 MW	Post-combustion (amine as a solvent) 90% efficiency			75-84% (GWP) 59% (GHG)-NGCC 81% (GHG)-IGCC 72%(GHG)-Super-PC
Viebahn <i>et al.</i> 2007	CC	N PC / IGCC	700 MW	88% capture efficiency	300 km pipeline		65% (CO ₂) 72% (CO ₂)
Suebsiri <i>et al.</i> 2009		C	882 MW	Post-combustion			87% (CO ₂)
Norway Singh <i>et al.</i> 2010	CC	NG	400 MW (55% efficiency)	Post-combustion (monoethanolamine as solvent)	500 km pipeline	90% sequestration from flue gas	70% (CO ₂) 64% (GWP)
Bauer and Heck, 2009		NG C					72-75% (GHG)
Spath and Mann, 2004							71% (GWP)
Modahl <i>et al.</i> 2009		NG					47-77% (GWP)
Korre <i>et al.</i> 2010		NG C					80% (GWP)

KEY	
IGCC	Integrated gasification combined cycle
CC	Combined Cycle
GWP	Global warming potential
NG	Natural Gas
C	Coal
PC	Pulverized Coal
GHG	Greenhouse gases

Upon reviewing the variations in reduction rates of CO₂ emissions by CCS-fitted fossil fuel power plants, in table 6-8 above, I have selected the following assumptions, for **CCS-fitted natural gas power plants (CCS-NG), CO₂ reduction is 70%**, for the **CCS-fitted crude oil power plants (CCS-CR), CO₂ reduction is 80%**, an assumed figure between CCS-NG and CCS-fitted coal power plants (which is an average of 90% in the literature). The assumed

in-between figure is also reflected in Table 6-9 below, presenting the content of Carbon in different fuels and therefore emissions from fuels powering power plants, oil is rightly positioned between coal and gas. In addition, this assumed figure shows consistency with ranges cited in the literature.

Carbon Dioxide Emission Factor:

Calculating the emission factor, also called emission intensity³⁰, of CO₂ in fossil fuel fired power plants follows a systematic approach. Here, different sources are provided from the literature presenting different but somewhat similar findings.

The amount of energy emitted during the combustion of fossil fuels depends on the amount of carbon, hydrogen and oxygen in the fuel. Hence, the ratio of carbon to convertible energy depends on these components in fuels that vary by fuel type. Typically, the carbon content in hard coal is 75%, oil 85%, natural gas 73%, however, the direct CO₂ emission from the combustion of these fuels are, in kg/MWh (kg/GJ), for hard coal 345 (95), oil 264 (73), natural gas 253 (70). Similarly, approximate life-cycle CO₂ emissions, including production, also in kg/MWh (kg/GJ), for hard coal 484 (134), for oil 350 (97), for natural gas 270 (75) (Biomass Energy Centre 2010).

Table 6-9 below shows a comparison between the emission factor of four fossil fuels, hard coal, lignite, oil and natural gas for GHGs for the 'upstream chains' only. He explains that:

“For fossil fuel technology options, upstream GHG emission rates can be up to 25% of the direct emissions from the power plant, whereas for most RETs and nuclear power upstream and downstream GHG emissions can account for over 90% of cumulative emissions” (Weisser 2007).

³⁰ Emission factor could include other gases besides CO₂, and emission intensity could take other aggregate activities into consideration such as GDP.

Table 6-9 GHG emissions factors from 'upstream' chains of fossil fuels used in Europe (Source: Dones *et al.* 2004 cited in Weisser 2007)

	Min (kg CO ₂ eq/kg fuel)	Max (kg CO ₂ eq/kg fuel)
Hard coal		
At producing region	0.04 (south. America)	0.34 (west. Europe)
Country specific supply mix	0.188 (Poland)	0.322 (Germany)
Supply mix UCTE		0.270
Lignite		
At mine		0.017
Oil		
Heavy fuel oil (west. Europe)		0.423
Light fuel oil (west. Europe)		0.480
Nat. gas		
West. Europe high pressure grid		0.491

Suebsiri uses lignite which is at **0.017** kg CO₂eq/kg fuel compared to **0.423** and 0.480 for heavy fuel oil and light fuel oil respectively. Lignite's emissions only form 4% of that from heavy fuel oil.

For clarification of terms, the sum of the emissions from all life-cycle stages is called *cumulative* emission. All processes and associated emissions but power plant operation are categorized in *upstream* (e.g. fuel exploration, mining, fuel transport) and *downstream* (e.g. decommissioning, waste management and disposal) groups. Emissions from power plant operation are referred to as direct. However, the different studies summarized here may use different boundaries (i.e. not consistent) for up- and downstream evaluation of production and energy chains, emissions for CCS technology to lie in the range of 92–145 gCO₂/kW h for pulverised coal technology, 65–152 gCO₂/kW h for IGCC and 40–66 gCO₂/kW h CCGT (Weisser 2007, p. 1551).

Table 6-10 Coal and NG Characteristics (Source: Odeh and Cockerill 2008)

Coal and natural gas characteristics				
Category	Coal		Natural gas	
Type and source	UK bituminous coal		North Sea Southern basin	
Composition (Berry et al., 1998)	Ash	15.0%	Methane	93.0%
	Moisture	12.0%	Ethane	3.0%
	Carbon	60.0%	Heavier alkanes	1.0%
	Hydrogen	3.9%	Nitrogen	2.7%
	Oxygen	6.0%	CO ₂	0.3%
	Sulfur	1.6%		
	Nitrogen	1.5%		
LHV, MJ/kg		24.5		49.2

Life cycle = Upstream (indirect) + power plant operation (direct emissions) + downstream (indirect)

An important finding is that although the application of CCS does substantially reduce GHG emissions from fossil fuel based electricity production, however, it also introduces additional GHG emissions due to material and energy uses and increases the upstream burdens per unit of electricity i.e. more CO₂ has to be captured and increase the cost of energy.

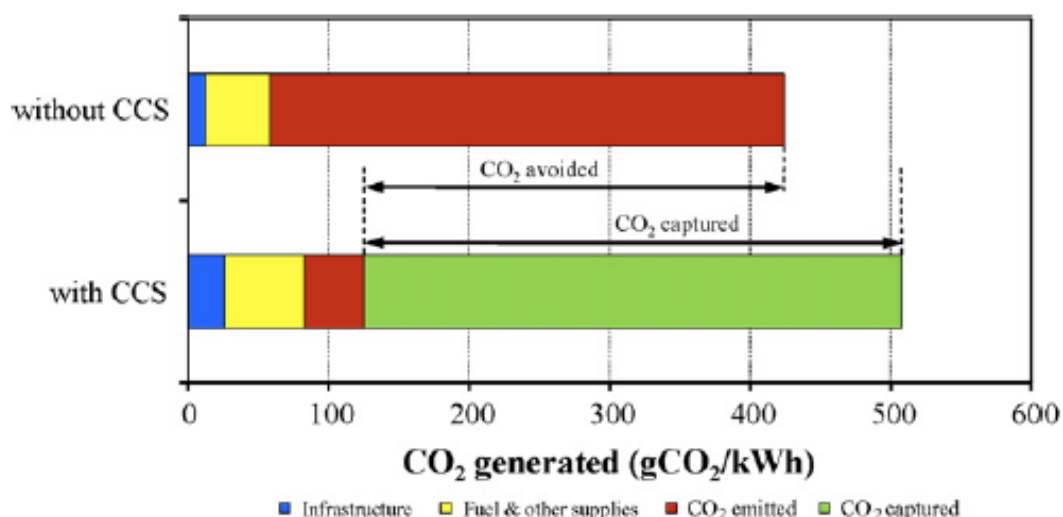


Figure 6-10 CO₂ accounting (Source: Singh et al. 2010)

Power generation emits significant amounts of GHGs, mainly CO₂. Sequestering CO₂ from the power plant flue gas can significantly reduce GHGs from the power plant itself, but this is not the total picture (Spath and Mann 2004):

“CO₂ capture and sequestration consumes additional energy, thus lowering the plant’s fuel-to-electricity efficiency. To compensate for this, more fossil fuel must be procured and consumed to make up for lost capacity. Taking this into consideration, the global warming potential (GWP), which is a combination of CO₂, methane (CH₄), and nitrous oxide (N₂O) emissions, and energy balance of the system need to be examined using a life cycle approach. This takes into account the upstream processes which remain constant after CO₂ sequestration as well as the steps required for additional power generation”

6.4 LCA Studies on Solar Photovoltaic Systems for Power Generation

There are numerous published studies in the literature studying life cycle energy and emissions from Solar PV systems, many of which are outdated. In this section, selected LCA studies (20), published over the last decade only since 2000 are summarised. Unlike LCA studies conducted on power generation with and without CCS, all Solar PV LCA studies are based on real cases, since Solar PV is today available at commercial sites, except for Azzorpadi and Mutale (2010) whom base their studies on future QD PV technology.

Table 6-11 Summary of Literature on Solar PV LCA studies

	Ref	PV technology	Assumptions	EPBT	gCO ₂ /kWh
1	Kannan <i>et al.</i> , 2006 Singapore	mc-Si			165
2	Sherwani <i>et al.</i> , 2010	a-Si sc-Si mc-Si		2.5–3.2, 3.2–15.5 1.5–5.7	15.6–50 44–280 9.4–104
3	Azzorpadi and Mutale, 2010	QD	25 years 10% conv. eff.	1.51	2.89 gCO ₂ -eq/kWh
4	Hondo 2005 Japan	a-Si			53.4
5	Alsema 2000 Italy	c-Si thin-film	3300 kW		50-60
6	Tripanagnostopoulou et al 2005 Greece	mc-Si	20 years 3 kW		104
7	Mason 2005 USA	mc-Si	3500 kW		184 kg-CO ₂ /kWp
8	Stoppato 2008				80 kg of equivalent CO ₂ /panel
9	Roes et al 2009	Polymer	25 yrs	0.93	727 (cited in A& M 2010) 132-819 g CO ₂ -eq for 1 PV device of 1 Wp.
10	Pacca et al 2007	PVL 136 a-Si KC 120 mc-Si		3.2 7.5	34.3 72.4
11	Bossert et al 2000	mc-Si a-Si a-(Si, Ge:H Thin-film Si Cu (in, Ga) (Se, S) ₂ CdTe Dye sensitized		4.1-2.3 1.9-3.0 4.7 1.8-1.3 0.9-0.5 1	
12	Knapp et al 2001	sc-Si CIS	30 yrs	4.1 2,2	
13	Greijer et al. 2001	Dye sensitized	20 yrs		19, 22, 25
14	Meijer et al. 2003	InGap/mc-Si InGap mc-Si	25 yrs	5.3 6.3 3.5	
15	Jungbluth et al. 2004	c-Si (sc/mc)	30 yrs	3.0-6.0	39-110
16	Peharz et al 2005	Con III-V multi-jun		0.67	
17	Raugei <i>et al.</i> 2007	CdTe CIS mc-Si	20 yrs	1.5 2.8 5.5-2.4-2.5	48 95 167-72-57
18	Veltkamp and de Wild-Scholten 2006	Dye sensitised		1.3–0.8-0.6	20–120
19	Alsema et al. 2006	mc-Si	30 yrs	1.8	32.5
20	Fthenakis and Alsema 2006	mc-Si CdTe	30 yrs	2.2 1.0/1.1	37 21/25-18

KEY	
EPBT	Energy pay back time
a-Si	Amorphous
sc-Si	Single/mono-crystalline
mc-Si	Multi/poly crystalline
CdTe	Cadmium telluride
CIS	Copper indium gallium (di)selenide
Con III-V multi-jun	FLATCON using III–V semiconductor multi-junction solar cells
QD	hybrid quantum dot (QD)-based solar cells

Clarifications of terms:

Energy Payback Times (EPBT) – Also known as ‘Energy Return on Energy Invested’, is a measure of the amount of energy a system needs to produce to repay the energy consumed during its manufacture. The period required for the renewable (solar) energy system to generate the same amount of energy (either primary or kWh equivalent) that was used to produce the system itself.

Solar PV Materials: monocrystalline or single crystalline silicon (sc-Si), polycrystalline or multicrystalline silicon (mc-Si), microcrystalline silicon, cadmium telluride, and copper indium selenide/sulfide

“The energy return factor (ERF), which is defined as the ratio between expected panel life (28 years) and EPBT. It represents how many times the plant pays back the energy needed for its production. In the best case, a photovoltaic plant can produce more than 8 times this energy.”
(Stoppato 2008)

Comparing Solar PV with CCS CO₂ Reduction Rates:

Figure 6-11 compares GHG-CO₂ equivalent emissions from different energy systems, to compare both systems of Solar PV and CCS, hence from the Figure, GHG emissions in CCS systems range from 40-280 (mean = 120) gCO₂-eq/kWh and Solar PV systems range from 40-76 (mean = 56) gCO₂-eq/kWh, approximately.

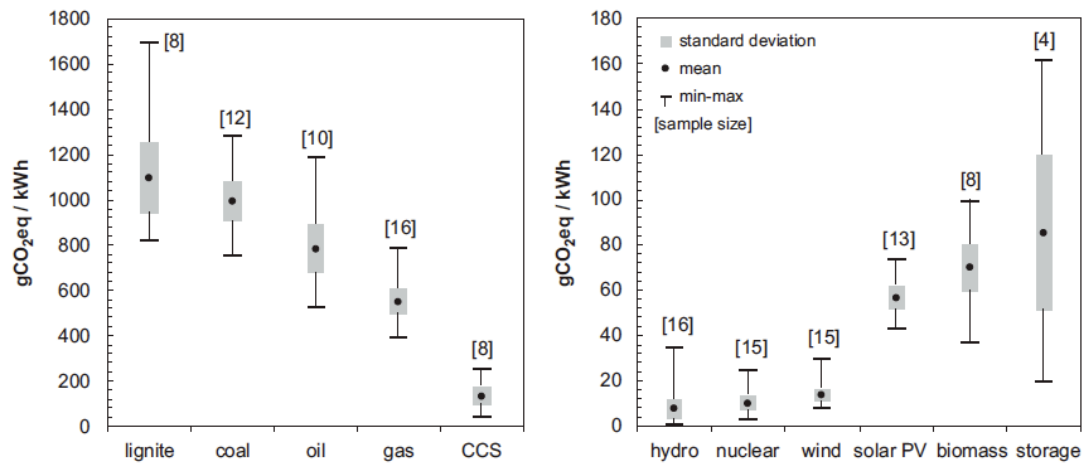


Figure 6-11 Summary of life cycle GHG from different energy systems (Source: Weisser 2007)

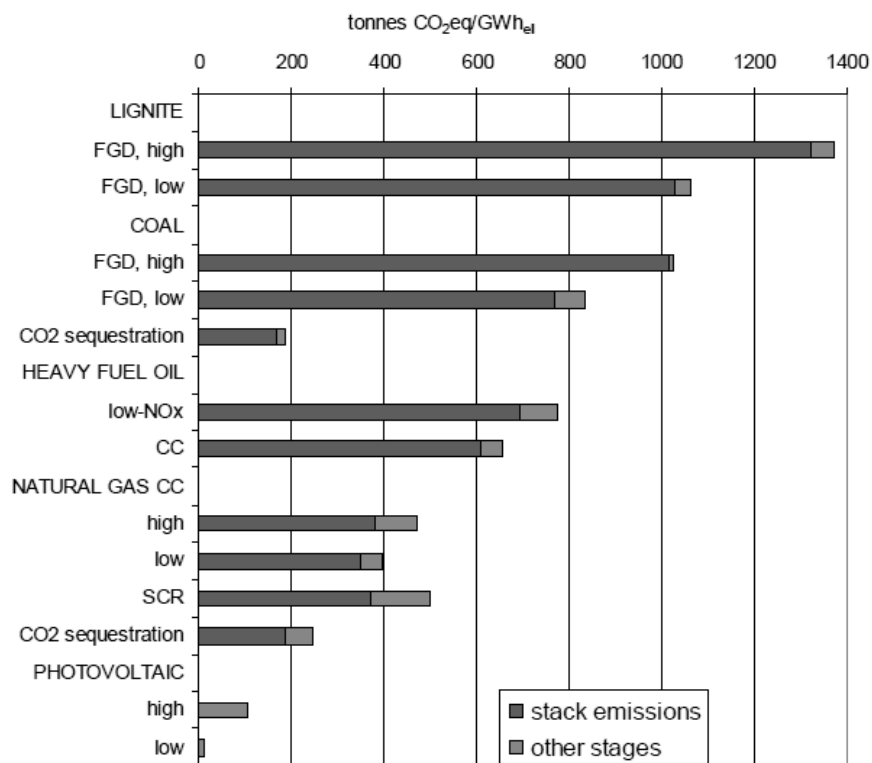


Figure 6-12 Comparison of fossil fuel systems and solar photovoltaic (Source: WEC 2004)

Figure 6-12 above is from a special report to World Energy Council (WEC 2004) that provides comparison for GHGs for fuel cycles with combined heat and power production (CHP). The total GHG are expressed as tonnes of CO₂ equivalent per 1 GWh. Stack is the direct emissions, and other stages include other stages of life cycle, the High and Low represents values from various LCA studies (WEC 2004, p. 7).

Solar PV ranges from 10-100 tonnesCO₂eq/GWh_{el} compared with fossil fuel systems that starts at 400-1400 approx.

Table 6-12 Carbon Dioxide Equivalent Emission Factor by Solar PV Type (Source: WEC 2004, p. 35 edited)

	Material	Capacity / MW	CO ₂ -eq t/GWh	Source
Australia	a-Si + mc-Si	400 kW	104	Nunn <i>et al.</i> , 2001
Germany	sc-Si	4.8 kW	55	ExternE, 1997
Germany	mc-Si	13 kW	51	ExternE, 1997
Italy	sc-Si	1 kW	43	Frankl <i>et al.</i> , 2004
Italy	mc-Si	1 kW	51	Frankl <i>et al.</i> , 2004
Italy	a-Si	1 kW	44	Frankl <i>et al.</i> , 2004
Italy	GIGS	1 kW	45	Frankl <i>et al.</i> , 2004
USA	a-Si	8 kW	12.5	Meier, 2002

Key

a-Si	Amorphous
sc-Si	Single/mono-crystalline
mc-Si	Multi/poly crystalline
CIGS	Copper indium gallium selenide

Based on the literature review, the assumed CO₂ reduction for this study is the rate of **95%** of Solar PV energy generation for the Saudi Arabian case study.

6.5 Introducing CCS and Solar PV to the Saudi Arabian Electricity Sector

In this section, the data source for the case study of Saudi Arabia, namely, the electricity generation forecasts, peak load and mean load, for three growth cases are explained. The assumptions of the study and the steps involved in generating the projected CO₂ emissions before and after applying cleaner energy technologies up to year 2025 are presented and explained.

6.5.1 Data Source

Information on the Saudi Arabian electricity sector is based on a report prepared by the Centre for Engineering Research at King Fahd University for Petroleum and Minerals (KFUPM) in Dhahran, Saudi Arabia, prepared for Electricity and Cogeneration Regulatory Authority (ECRA) in Riyadh, Saudi

Arabia. The report is entitled “*Updated Generation Planning for Saudi Electricity Sector*” and it is published in 2006.

The purpose of their study was to develop a viable Electricity Generation Plan for the Kingdom of Saudi Arabia over the next 15 years (2008-2023). The method they used for calculating the demand forecast is the multiple regression analysis from historical annual energy and economic data, namely, population and Gross Domestic Product (GDP). Their data were collected from the Ministry of Water and Electricity, Ministry of Planning, Electricity and Cogeneration Regulatory Authority (ECRA), Saudi Electricity Company (SEC), Saline Water Conversion Corporation (SWCC), and Independent Power Producers (IPP). A Multi-Area Reliability Analysis Program (MAREL) was used to develop the generation plan (KFUPM 2006a; 2006b).

6.5.2 Assumptions

From the report, three scenarios for electricity generation forecast were prepared (KFUPM 2006a), based on three GDP growth cases, most likely growth, high growth and low growth scenarios. The study also presents its findings for each region in the Kingdom, Eastern Operating Area (EOA), Western Operating Area (WOA), Central Operating Area (COA), and Southern Operating Area (SOA) and Isolated Operating Area (IOA).

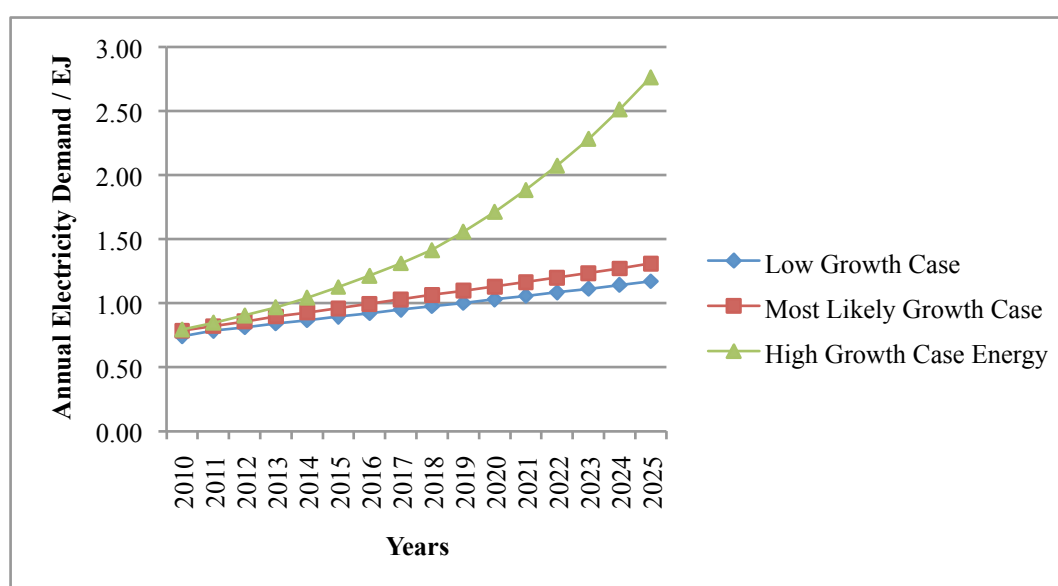


Figure 6-13 Annual Saudi Electricity Demand Forecast in EJ (2010-2025)

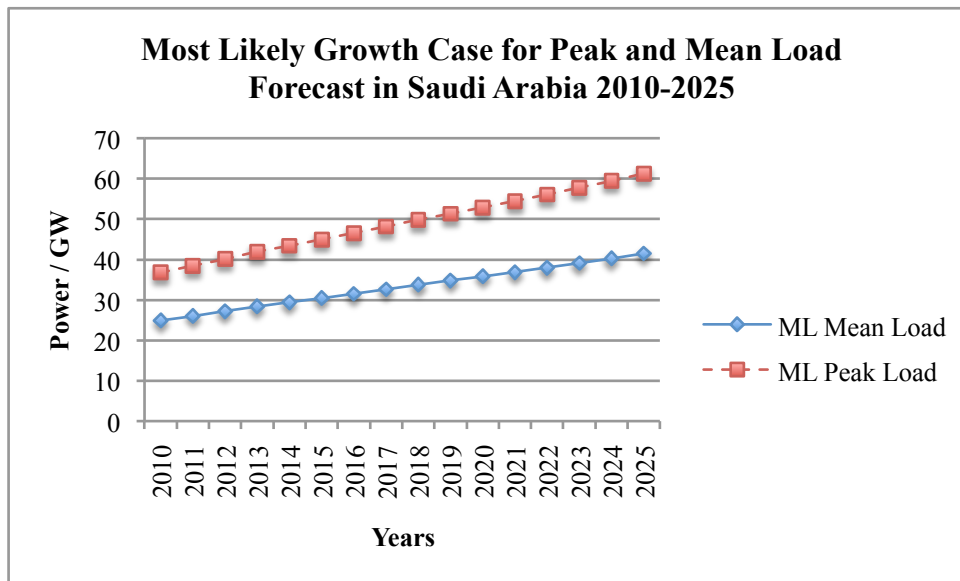


Figure 6-14 Most Likely Growth Case for Peak and Mean Load Forecast in Saudi Arabia 2010-2025 in GW

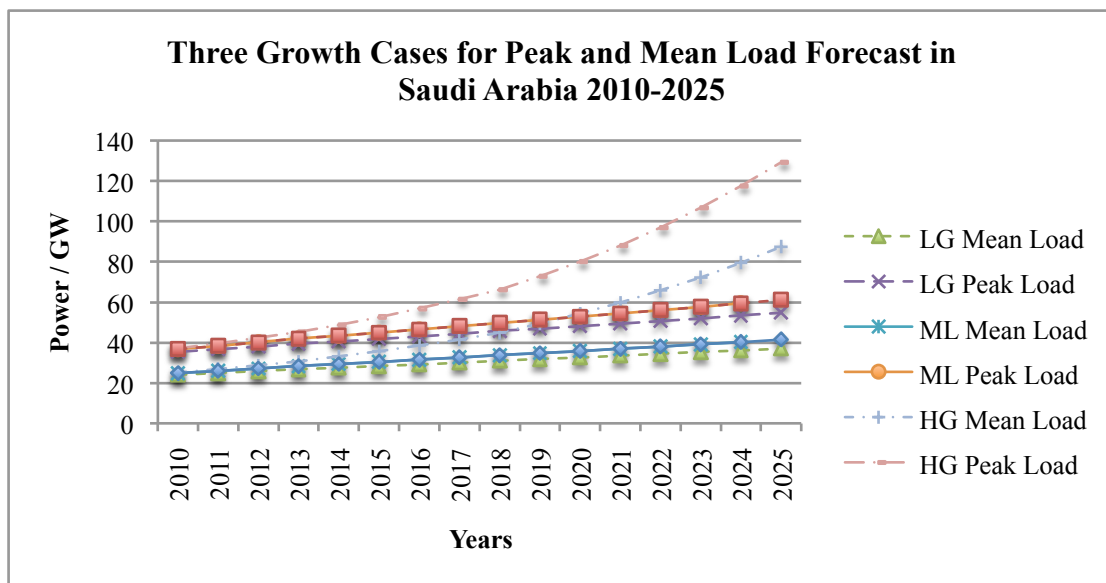


Figure 6-15 Three Growth Cases for Peak and Mean Load Forecast in Saudi Arabia 2010-2025 in GW

The Kingdom's Most Likely Case Electricity Forecast (2010-2025):

Table 6-13 The Kingdom's Electricity Forecast, 2010-2050 (Most Likely Growth Case)

Most Likely Case					
	1	2	3	4	5
	Growth Rate	Energy / GJ	Carbon Emissions / t CO ₂	Mean Load / MW	Peak Load / MW
2010	4.27%	786,183,000	176,340,068	24,930	36,794
2011	4.27%	821,250,000	183,869,789	26,042	38,435
2012	4.27%	857,882,000	191,721,029	27,203	40,149
2013	4.27%	896,148,000	199,907,517	28,417	41,940
2014	3.52%	927,692,000	206,944,261	29,417	43,416
2015	3.52%	960,347,000	214,228,699	30,452	44,945
2016	3.52%	994,151,000	221,769,550	31,524	46,527
2017	3.52%	1,029,145,000	229,575,838	32,634	48,164
2018	3.52%	1,065,371,000	237,656,907	33,783	49,860
2019	2.99%	1,097,226,000	244,762,849	34,793	51,351
2020	2.99%	1,130,033,000	252,081,258	35,833	52,886
2021	2.99%	1,163,821,000	259,618,488	36,905	54,467
2022	2.99%	1,198,619,000	267,381,080	38,008	56,096
2023	2.99%	1,234,457,000	275,375,775	39,144	57,773
2024	2.99%	1,271,368,000	283,609,510	40,315	59,500
2025	2.99%	1,309,382,000	292,089,435	41,520	61,279

Assumptions and Explanations:

The Most Likely Growth Case for the Saudi Arabian electricity forecast is presented here, the two other cases³¹, High Growth Case and Low Growth Case will be used for setting the boundaries for the forecast, as shall be presented later. Details on the assumptions, calculations and explanations for each column are as follows:

³¹ Please refer to Appendix for full table on High Growth and Low Growth Cases.

1. Column (1) “Growth Rate” presents the rate of growth in the year for electricity generation in the Kingdom, based on the Most Likely Growth Case. The timescale is based on a five-years period, three cases are presented in Table 6-14 below, High Growth Case, Most Likely Growth Case, and Low Growth Case. From the reported study in-use (KFUPM 2006a), the forecast is done for the period 2008-2023, it is explained:

“The high growth estimate is the GDP as provided by the Ministry of Planning for the entire study duration. The most likely growth scenario forecast is based on maintaining the same slope of the GDP growth as up from the year 2004 and forward. The low growth estimate is obtained by reducing the slope of the GDP for each year by 20% as compared to the most likely case.” (KFUPM 2006a, p. 5)

The table illustrates the growth rate used for the study period, the same pattern of trends is continued to generate growth rates up to year 2025. It is assumed that the two years, 2024 and 2025 will fall under the same growth rate for the start year of the period, year 2019, for the Most Likely Growth Scenario, this is 2.99% for the period 2019-2025.

Table 6-14 Electricity Growth Rate for Three Cases for Saudi Arabia 2008-2050

Period	High Growth Case / %	Most Likely Growth Case / %	Low Growth Case / %
2008 – 2013	6.33	4.27	3.54
2014 – 2018	7.91	3.52	3.01
2019 – 2025	10.03	2.99	2.61

2. Column (2) “Energy”, measured in gigajoules (GJ), represents the units of energy produced for a particular year. Year 2008 Energy forecast is used from the reported study in-use (KFUPM 2006a), Equation 1 is then applied to calculate figures for the remaining years using the growth rate in Column (1). Expressed in the following equation:

Equation 1 Calculating Energy, Peak Load, and Mean Load

$$X_y = X_{y-1} + Z_y(X_{y-1})$$

Where: X_y = Peak Load, Mean Load or Energy for year Y; Z_y = Rate of Growth for Y; Y = Current Year

3. Column (3) “Carbon Emissions” shows the total carbon dioxide emissions from the electricity sector in Saudi Arabia for a particular year. For calculating the carbon emissions, the Emission Factor of 0.816 t/MWh was used, as explained earlier, which was published for Saudi Arabia for the period 1999-2002 by the US Department of Energy³² (EIA 2007).

Equation 2 Calculating Carbon Dioxide Emissions

$$M = E \cdot X$$

Where: **M** = Annual Carbon Emissions in t; **E_y** = Power Demand in GWh; **x** = CO₂ emission factor of 816 t/GWh

4. Column (4) “Mean Load” presents the *average* load of electricity required over a particular year in MW. Calculated using Energy capacity units of that year (GWh) divided by a year’s hours (356 days x 24 hours = 8760), like Column (1), figures for the remaining years are calculated using Equation 1,
5. Column (5) “Peak Load” provides the forecast for peak load, the highest electricity demand within a particular year in megawatt (MW), the 2008 figure is taken from the report and figures for the remaining years in Column (2) are calculated based on the growth rate in Column (1),

For the full table for High Growth Case and Low Growth Case please refer to Appendix.

The following graph shows the three cases for carbon dioxide emissions (in million metric tonnes of CO₂) of the Saudi Arabian electricity forecast without

³² U.S. Energy Information Administration, based on data from the following sources: International Energy Agency (IEA), *Electricity Information Database 2007* and *CO₂ Emissions from Fuel Combustion Database 2006*, <http://www.iea.org>, October 2007.

introducing any environmental measures (i.e. without applying CCS or solar energy technologies):

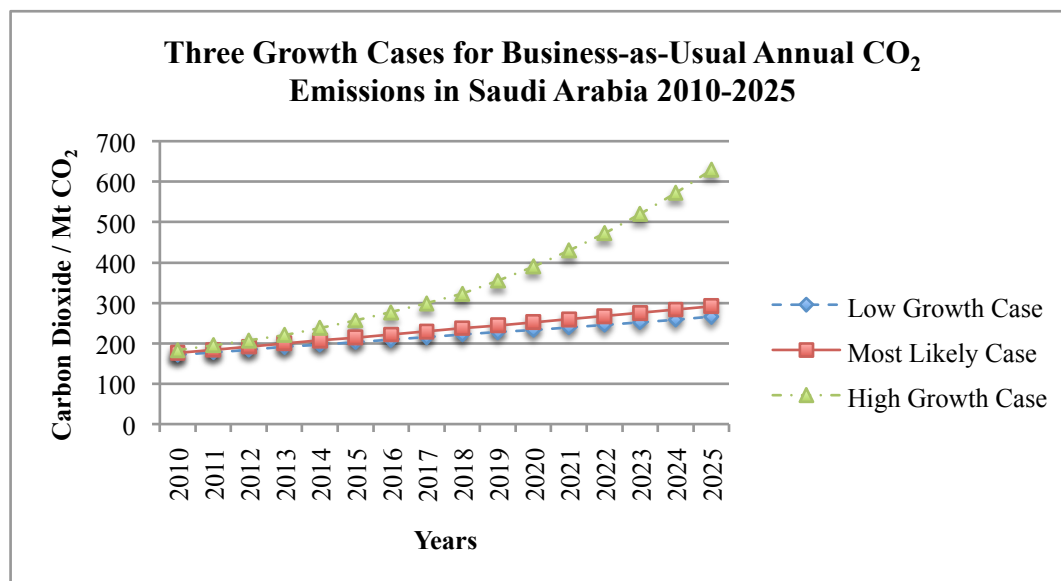


Figure 6-16 Three growth cases forecast for carbon dioxide emissions (in million metric tonnes of CO₂) from Saudi Arabia's Electricity sector (2010-2025)

Calculating the Energy Mix

Saudi Arabia's current electricity mix (2007) is presented in the pie chart below:

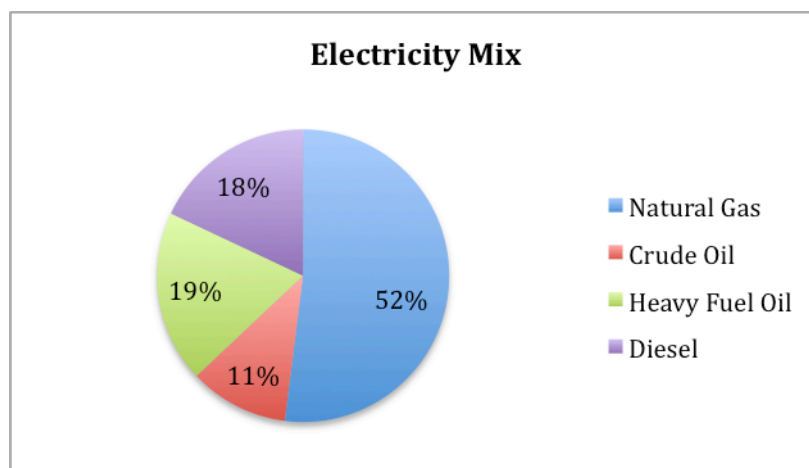


Figure 6-17 Saudi Electricity Mix in 2007 of an Actual Load of 34 GW (Source: data from ECRA 2008; 2009)

The energy mix for 2007 is shown in Figure 6-17, merging Diesel (18%) and Heavy Fuel Oil (19%) and to Crude Oil (11%), gives a total of %48, with the remaining electricity generation met by Natural Gas (NG) at 52%.

“The general policy regarding the fuel is to use crude oil as the basic fuel for the gas turbines. However, in the eastern region natural gas is used for most of the power plants. Diesel oil is used for some small gas turbines. The steam turbine at Rabigh and Shaiba uses heavy fuel oil as the basic fuel. There are adequate reserves of crude oil to meet the growing demand of fuel for power generation.” (KFUPM 2006a)

The study in-use assumes the availability of specific fuel types for different operating areas across the Kingdom (KFUPM 2006a, p. 28):

“For this study it will be assumed that the existing generating units will continue burning the same fuel type. However, for the future units it will be assumed that natural gas would be available for the eastern and central operating areas. As for western and southern operating areas it will be assumed that they would be using liquid fuel for the study period. The diesel units in the isolated system would use crude oil as a primary fuel.”

6. The energy mix in Figure 6-17 is assumed to remain constant for the duration of the study.
7. Using the LCA studies summarised for both CCS and Solar PV technologies, the assumed CO₂ reduction rate is follows in the table:

Table 6-15 Assumed CO₂ Reduction Rates for CCS and Solar PV Applications for this study

Power Generation System	CO₂ Reduction Rate
CCS-Installed CR-power plants	80%
CCS-Installed NG-power plants	70%
Solar PV	95%

Figure 6-18 shows the results of applying CCS technologies, first (red square) to new power plants only i.e. to the new replaced power plants (decommission rate of 2%) as well as the new demands, as per Table 6-13, and second (green triangle) on the entire electricity sector, the capacity of both existing power plants and new demand. It is theoretically feasible, since the technologies of CCS are end-of-pipe technologies, as explained in Chapter 5, and do not require the replacement of power plants but rather the addition of new procedures as well as installation of facilities on the existing power plants and infrastructure.

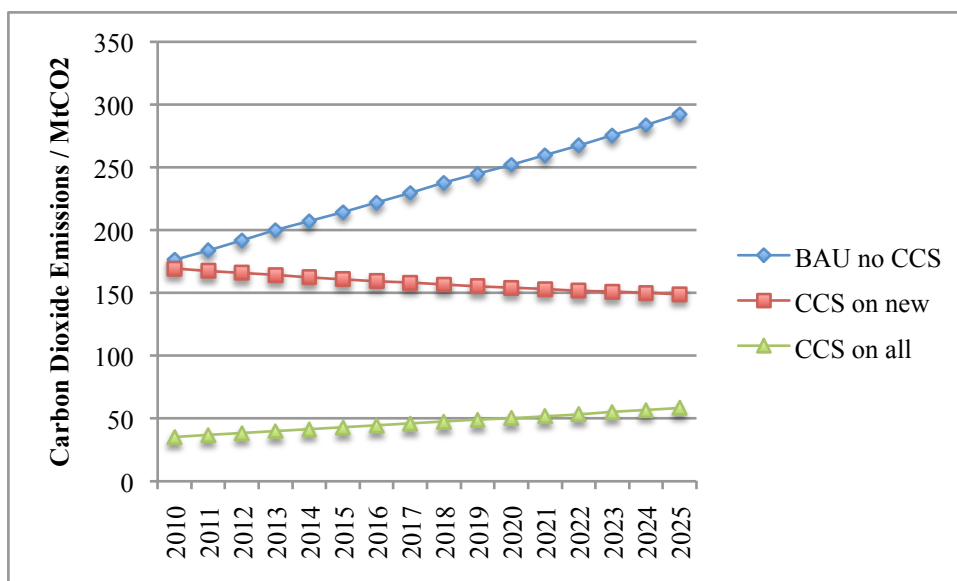


Figure 6-18 Most Likely growth Case Carbon emissions with and without CCS installed on new (red square) and all (green triangle) power plants at the future energy mix, in million metric tonnes of CO₂

Comparing the three cases for applying CCS on new power generation capacity only, gives the result in Figure 6-19, and comparing the three cases for applying CCS on the entire power generation capacity, gives the results in Figure 6-20:

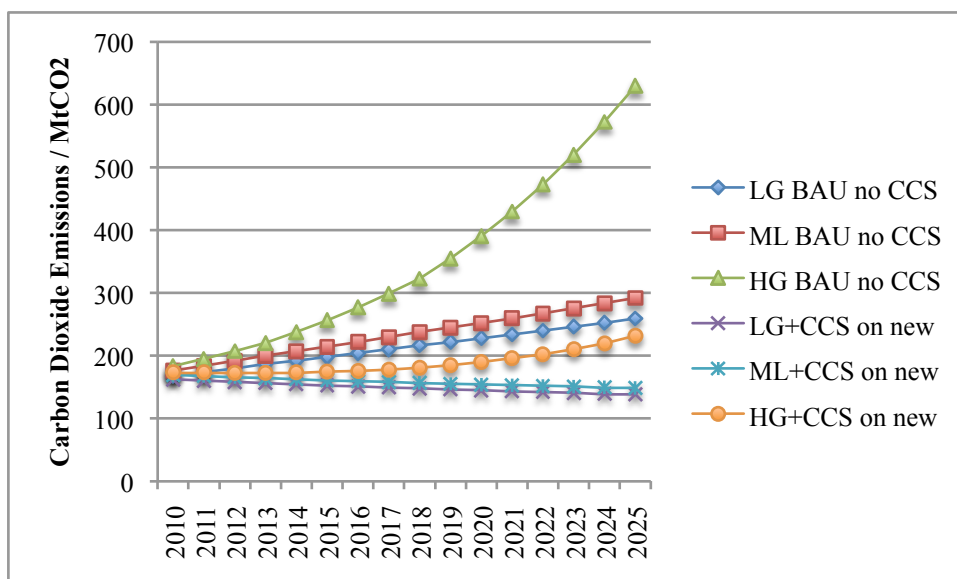


Figure 6-19 Three Cases for Applying CCS to new power generation capacity only

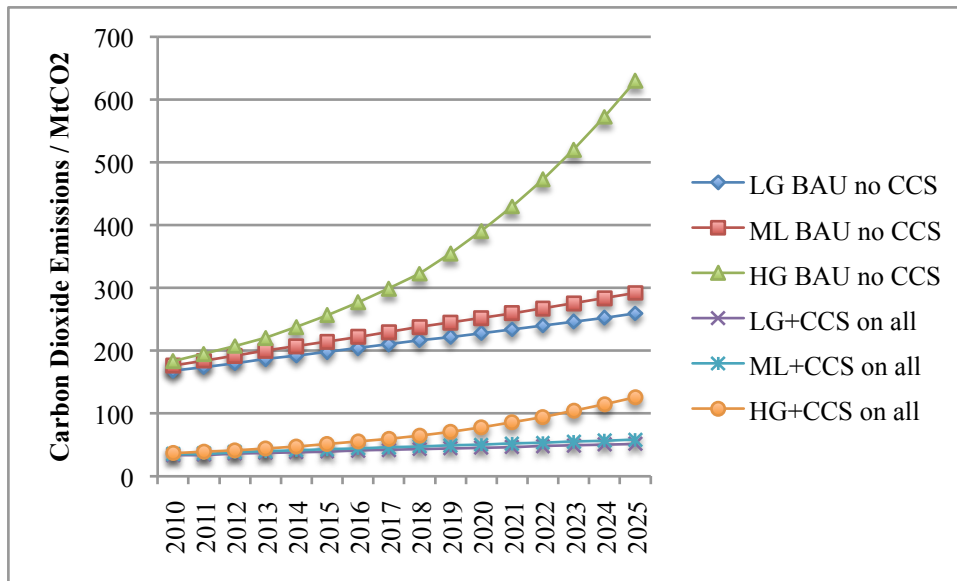


Figure 6-20 Three Cases for Applying CCS to all power generation capacity

CCS Reductions

CCS-fitted power plants promises to reduce carbon emissions by 70-80% depending on the fuel type used in the power plant. From the LCA literature summarized before, we learnt that CCS-fitted natural gas-fuelled power plants (CCS-NG) reduce carbon emission by 70%, and CCS-fitted crude oil-fuelled power plants (CCS-CR) reduce carbon emissions by 80%.

Deciding which energy mix to use is important because it will determine the factor at which the CCS-installed power plants will reduce the carbon emissions.

To calculate the CCS energy mix carbon reduced emission rate, we need to use the life cycle CO₂ emissions of crude oil and natural gas. As we have seen before (pg. 207), life cycle CO₂ emissions of crude oil is 350 kg/MWh and that of natural gas is 270 kg/MWh, and therefore, to calculate the life cycle CO₂ emissions of natural gas from life cycle CO₂ emissions crude oil, the factor to use is 0.77 (270/350), as used in the following equation.

Equation 3 Calculating the CCS-scenario Carbon Reduction Emission Rate - Calculating X_{CR} and X_{NG} and Y

$$\begin{aligned}
 X &= 0.48X_{CR} + 0.52X_{NG} \\
 816 &= 0.48X_{CR} + 0.52X_{CR} \cdot 0.77 \\
 X_{CR} &= \frac{816}{0.52 \cdot 0.77 + 0.48} \\
 X_{CR} &= \frac{816}{0.88} \\
 X_{CR} &= 927 \\
 X_{NG} &= 714 \\
 Y &= 0.2(0.48 \cdot 927) + 0.3(0.52 \cdot 714) \\
 Y &= 88.99 + 111.38 \\
 Y &= 200 \text{ kg CO}_2 / \text{MWh} \\
 Y &= 0.200 \text{ t CO}_2 / \text{MWh}
 \end{aligned}$$

Where **X** = BAU Emission factor of 0.816 tCO₂/MWh; **Y** = CCS-Scenario emission reduction; **CR** = Crude Oil (including Heavy Fuel Oil and Diesel); **NG** = Natural Gas

Decommission Rate

In this study, the same assumptions of “decommission rate” that is stated in the report in-use will be used, it is explained as follows (KFUPM 2006a, p. 36):

Based on the economic life of the generating units, a large number of the generating units have reached the end of their economic life. These retired units have to be replaced by new generating units in addition to the units required to meet the load. This would place severe financial requirements in order to meet the reliability criteria of 4.8 hours/year. Moreover, it is not practically feasible to retire a large number of units at a particular time. In order to meet this special requirement, it is proposed to delay the retirements of the existing units and to adopt the following policy:

- *No units would be retired up to the year 2009.*
- *After 2009, units would be retired gradually. The capacity to be retired during a particular year should not exceed 2% of the installed capacity in that operating area for that year.*

Calculating the new emissions after applying the decommission rate of 2% per year, therefore, CCS-installed power plants will be replaced 2% in

addition to the new energy demand, all at the new energy mix (of 48% CR and 52% NG, CCS reducing carbon at 76.1%), the following equation is generated:

Equation 4 Calculating total electricity emissions of CO₂ with CCS introduction to new power plants only

$$M_n = (1 - z)^n B_0 + az(1 - z)^x B_0 + a(B_{n+1} - B_0)$$

Where, **M** = Emissions of CO₂ per year *n* with CCS; **B₀**= 169 MtCO₂/a; **n** = {1, 2, 3, ...}; **z** = 0.02 decommission rate per year *n*; **a** = ratio of CO₂ reduction through CCS = 0.252; **B_n** = Business-as-usual Emissions of CO₂ per year *n*

Emissions of Electricity Generation with and without CCS: Before 2011, no CCS or decommission has been applied and emissions remain the same, as explained from the report in-use above. The CCS scenario is applied using Equation 4 from 2011 onwards, i.e. applied to the 2% (of decommissioned power plants) + to the New Demand. The remaining 98% of old Power Plants remain the same, with no CCS installations. The new energy mix (39% NG and 61% CR, total reduction of 76.1%) is kept as a constant throughout the years 2011-2025. The result showed a reduction of emissions at approximately 4%.

Energy Efficiency measures: Due to energy efficiency loss by the application of CCS and solar, energy capacity reduction due to increased inefficiency must be taken into account. In the literature, a capacity reduction of 25-30% is assumed owed to the introduction of cleaner energy technologies, namely, CCS and Solar: 25% Alajlan *et al* (1997), 30% IEA (2005), and 30% Alsaleh (2008). In this study **no efficiency energy losses** are assumed.

6.5.3 Introducing Solar to the Saudi Energy Mix:

In this section, Solar PV is introduced to the Saudi energy mix, figure 6-21 shows the new energy mix, assumed at 10% Solar, 47% NG and 43% CR, this is calculated by keeping the same proportions in fossil fuels as per figure 6-16, i.e. out of 100% fossil fuels, 52% NG and 48% CR (including D, HFO and CR), where fossil fuels now meet 90%, the energy mix is as follows:

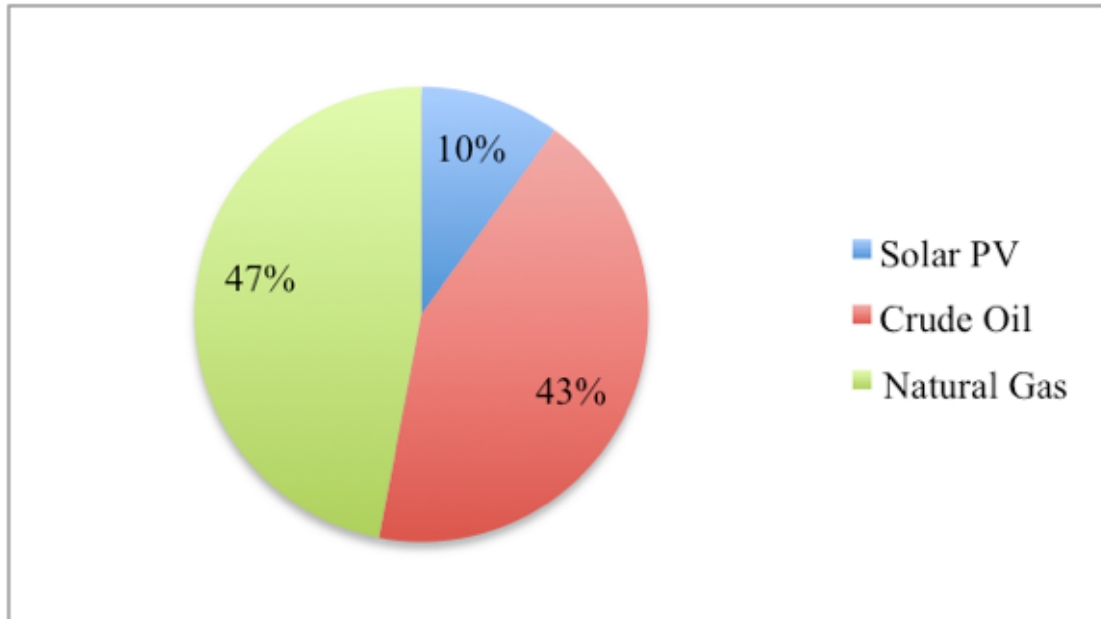


Figure 6-21 Introducing Solar to the future energy mix of Saudi Arabia's electricity sector

Carbon reductions:

For this new energy mix calculating the total CO₂ emission reduction rate through the reduction rates by: Solar = 95%, CCS-CR = 80%, CCS-NG = 70% - Calculating X_S using Solar PV reduction rate as discussed earlier, 56 gCO₂-eq/kWh (p. 211), gives the following:

Equation 5 Calculating CO₂ Emission Reduction Rate at New Energy Mix at 10% Solar and 90% CCS

$$\begin{aligned}
 Y &= 0.2(0.432X_{CR}) + 0.3(0.468X_{NG}) + 0.05(0.1X_S) \\
 Y &= 0.2(0.432 \cdot 927) + 0.3(0.468 \cdot 714) + 0.05(0.1 \cdot 56) \\
 Y &= 0.2(400) + 0.3(334) + 0.05(5.6) \\
 Y &= 80 + 100.2 + 0.28 \\
 Y &= 180 \text{ kgCO}_2 / \text{MWh} \\
 Y &= 0.180 \text{ tCO}_2 / \text{MWh}
 \end{aligned}$$

Where: **X** = BAU Emission Factor (0.816); **Y** = New Energy Mix Factor; **CR** = Crude Oil; **NG** = Natural Gas; **S** = Solar.

Figure 6-22 presents the results of producing 10% of total electricity by Solar PV and 90% by CCS-fossil fuels (47% NG and 43% CR, which groups CR, HFO, and D), these cleaner energy mechanisms are applied to new power

generation only with a decommission rate of 2%, therefore, the new cleaner energy replaces the decommissioned power plants, and a further cleaner energy generation will meet the new demands.

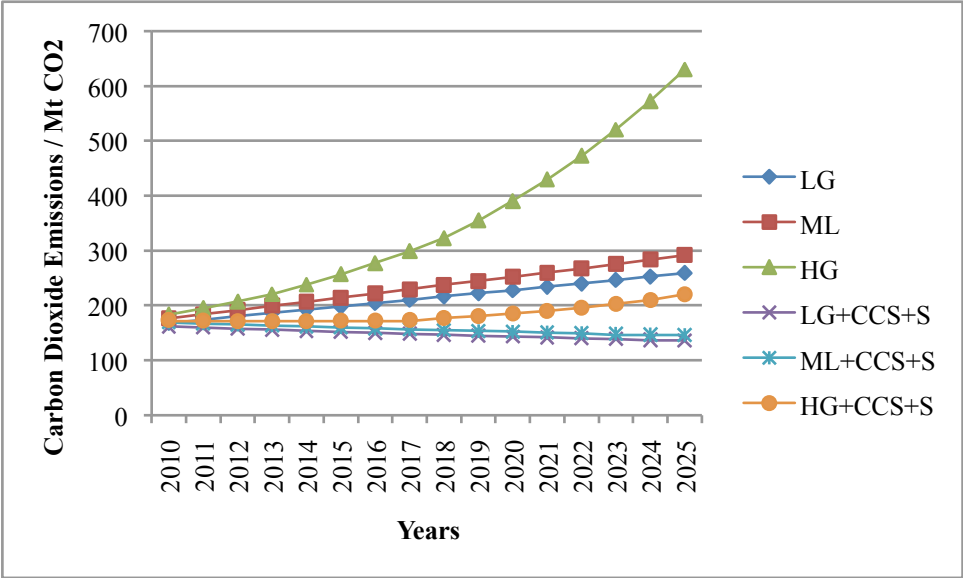


Figure 6-22 Carbon Emissions (in million metric tonnes of CO₂) from Three Growth Cases of new energy mix at 90% CCS and 10% Solar on new power generation only

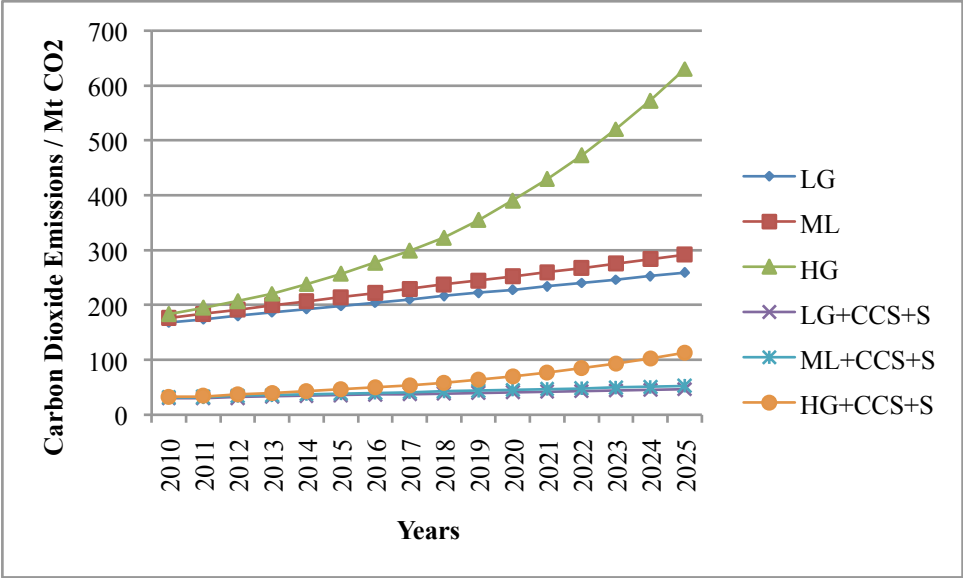


Figure 6-23 Carbon Emissions (in million metric tonnes of CO₂) from Three Growth Cases of CCS and Solar on all power generation

KEY

LG	Low growth case
ML	Most likely growth case
HG	High growth case

S	Solar
CCS	Carbon capture and storage

Figure 6-23 present the results of generating 10% of total electricity by Solar PV and 90% by CCS-fossil fuels, as per the energy mix in figure 6-21. These cleaner energy mechanisms are applied to the full capacity of power generation.

Therefore, introducing 10% of Solar PV in the energy mix and keeping CCS-fossil fuels at the remaining 90% of power generation shows a slightly more reduction of CO₂ emissions compared to that of 100% CCS fossil fuel power generation (figures 6-19 and 6-20). In the first scenario of figure 6-23 which considers the three growth cases, 10% Solar PV and 90% fossil fuel CCS reduces CO₂ from 630 MtCO₂ to 124 MtCO₂, saving up to a total of **506 MtCO₂** for year 2025, this is approximately the same saving amount to be achieved by 100% fossil fuel CCS (505 MtCO₂).

Furthermore, introducing the same energy mix of 10% Solar PV and 90% CCS-fossil fuels, considering three growth cases, applying these cleaner energy mechanisms to the *entire* power generation capacity reduces CO₂ emissions from 630 MtCO₂ to 57 MtCO₂, saving up to a total of **573 MtCO₂** for year 2025, this is slightly more than the amount to be saved by 100% fossil fuel CCS (555 MtCO₂).

In this section, to see a more vivid effect of Solar PV, the energy mix is switched to 90% Solar PV and 10% fossil fuels with CCS. So, the new energy mix to be used in the following section is: 90% Solar PV, 10% CCS-fossil fuels, of which 4.8% is CR (including D, HFO and CR), and 5.2% is NG.

Figure 6-24 presents the results of applying this new energy mix using equation 6 in three growth cases, where the total electricity is met by 90% Solar PV and 10% CCS-fossil fuels, all applied to new power generation capacity at a decommission rate of 2%, so these cleaner energy technologies replace 2% of the decommissions power plants and also to meet new energy.

With the installation of CCS to fossil fuel power plants and Solar to energy generation, this gives a total carbon reduction rate of 93.1% calculated below:

Equation 6 Calculating CO₂ Emission Reduction Rate at New Energy Mix at 90% Solar and 10% CCS

$$\begin{aligned}
 Y &= 0.2(0.048X_{CR}) + 0.3(0.052X_{NG}) + 0.05(0.90X_S) \\
 Y &= 0.2(0.048 \cdot 927) + 0.3(0.052 \cdot 714) + 0.05(0.90 \cdot 56) \\
 Y &= 8.9 + 11.1 + 2.5 \\
 Y &= 22.5 \text{ kgCO}_2 / \text{MWh} \\
 Y &= 0.0225 \text{ tCO}_2 / \text{MWh}
 \end{aligned}$$

Introducing Solar at 90% of the energy mix for power generation and CCS at 10%, the following forecast is presented, Figure 6-24 shows the introduction of these to only new power generation capacities, whereas Figure 6-25 shows the introduction to all existing power generation,

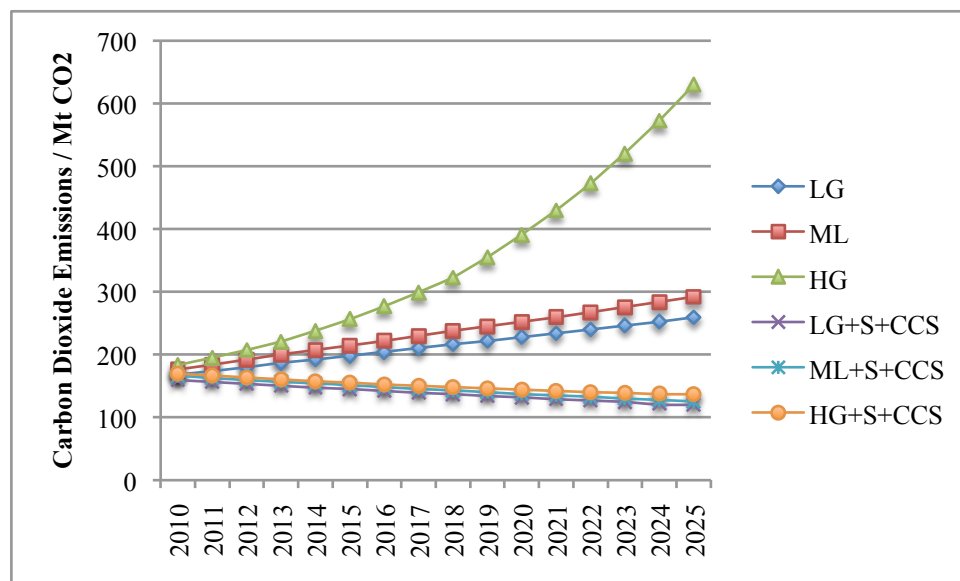


Figure 6-24 Carbon Emissions (in million metric tonnes of CO₂) from Three Growth Cases of new energy mix at 10% CCS and 90% Solar on new power generation only

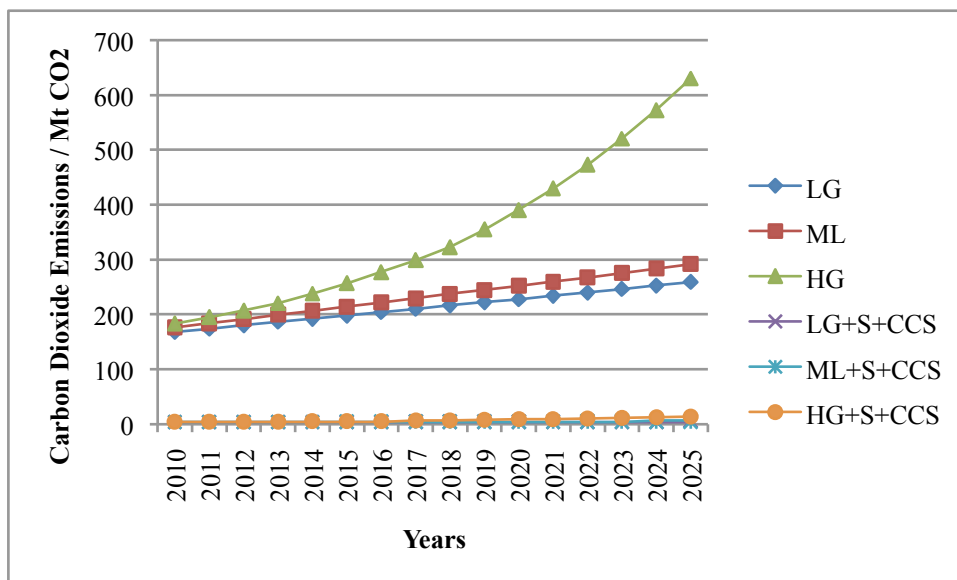


Figure 6-25 Carbon Emissions (in million metric tonnes of CO₂) from Three Growth Cases of new energy mix at 10% CCS and 90% Solar on all power generation capacities

KEY

HG	High growth case
ML	Most likely growth case
LG	Low growth case
S	Solar
CCS	Carbon capture and storage

Figure 6-25 presents the results of applying this new energy mix in three growth cases, where the total electricity is met by 90% Solar PV and 10% CCS-fossil fuels, applied to the *entire* power generation capacity.

Discussion and Analysis

This study has examined the profile of the Saudi electricity sector to illustrate possible transition paths towards cleaner energy generation and focused on two cleaner energy technology options, CCS and Solar PV.

Key:

BAU	Business-as-usual with no cleaner energy additions
CO ₂	Total CO ₂ emissions per year
Savings	Total CO ₂ emissions savings per year

On all	Added/Retrofitted on all power generation capacity
On new	On new demands power generation capacity only
CCS	100% CCS-fossil fuels
CCS+S	90% CCS + 10% Solar PV
S+CCS	90% Solar PV + 90% CCS

Table 6-16 Forecasted CO₂ emissions and CO₂ savings in all scenarios for year 2025 in million tons of CO₂ highlighting the most plausible option.

Yr 2025		Low Growth		Most Likely Growth		High Growth	
		/MtCO ₂		/MtCO ₂		/MtCO ₂	
BAU no CCS		259		292		630	
		CO ₂	Savings	CO ₂	Savings	CO ₂	Savings
1	CCS on all	52	207	58	234	126	504
2	CCS on new	139	120	149	143	232	398
3	CCS+S on all	47	212	52	240	113	517
4	CCS+S on new	136	123	146	146	220	410
5	S+CCS on all	6	253	7	285	14	616
6	S+CCS on new	120	139	125	167	137	493

Table 6-16 provides a summary of the current study, it presents all the scenarios and cases for year 2025 which is the last year of the duration of this study and therefore shows the greatest savings of CO₂.

The study included six scenarios for the three growth cases, and in total presented eighteen different forecast figures for CO₂ emissions generated by electricity for Saudi Arabia for each year from 2010-2025. Year 2025 is taken as an example to be discussed below:

Row 1. Energy mix was kept at 100% fossil fuels (52% NG and 48% CR) and all existing and new power plants were fitted with CCS. This reduced BAU CO₂ emissions from 259 MtCO₂ to 52, saving 207 MtCO₂ in LG, and from 292 MtCO₂ to 58, saving 234 in ML, and from 630

MtCO₂ to 126, saving 504 MtCO₂ in HG. Although this scenario is technically feasible it is not economically viable, hence it is not a plausible solution to fit CCS in each of the existing power plants, some of which are very old and inefficient and therefore it would not be economically efficient to introduce CCS towards the end of the lifecycle of old power plants.

Row 2. Energy mix was kept at 100% fossil fuels (52% NG and 48% CR) and CCS is fitted this time to new power plants only, keeping existing power plants without adding any cleaner energy technologies. Considering a 2% decommission rate for power plants per year and a growth rate in energy use for year 2025 of 2.61% for LG, 2.99% for ML and 10.03% for HG. This reduced BAU CO₂ emissions from 259 MtCO₂ to 139, saving 120 MtCO₂ in LG, and from 292 MtCO₂ to 149, saving 143 MtCO₂, in ML and from 630 MtCO₂ to 232, saving 398 MtCO₂ in HG. This scenario is technically feasible, economically viable and presents a plausible solution for Saudi Arabia as it is possible to fit CCS to new power plants more readily than to existing ones and because fossil fuel is readily available to meet rising local demand, more CO₂ will be produced if not coupled with introducing CCS systems.

Row 3. Energy mix was changed by introducing Solar PV at 10% and reducing fossil fuels to 90% (47% NG and 43% CR). CCS and Solar PV were fitted to the entire energy generation capacity. This scenario reduced BAU CO₂ emissions from 259 MtCO₂ in LG to 47, saving 212 MtCO₂, and from 292 MtCO₂ in ML to 52, saving 240 MtCO₂, and from 630 MtCO₂ in HG to 113, saving 517 MtCO₂. Introducing Solar PV to the energy mix even at 10% and then showed more savings compared to Row 1, although it is feasible to meet electricity generation by Solar PV at 10%, however, CCS and Solar PV application to the entire power generation capacity remains an implausible solution and unviable economically, as argued before.

Row 4. Energy mix was kept the same as the previous scenario, fuelling power generation by 90% fossil fuels (47% NG and 43% CR) with CCS and 10% Solar PV applied to new power generation capacity only.

Here, existing power plants are kept the same based on fossil fuels with no cleaner energy mechanism being introduced, CCS and Solar PV were fitted to new power generation only, considering the same decommission rate of old power plants and growth rates as Row 2. This reduced BAU CO₂ emissions from 259 MtCO₂ in LG to 136, saving 123 MtCO₂, and from 292 MtCO₂ in ML to 146, saving 146 MtCO₂, and from 630 in HG to 220, saving 410 MtCO₂. This seems to be the most economically viable option and a most plausible solution from the six scenarios (rows). Existing power plants remain the same, CCS is introduced only to new power plants and Solar PV is utilized at 10% for power generation. This way, rising local energy demands can be met by Solar PV complimented by CCS-fossil fuels, more oil could be exported to global oil markets, and CO₂ emissions will be reduced greatly.

Row 5. Energy mix here was inversed to 90% Solar PV and 10% fossil fuels (5.2% NG and 4.8% CR) with Solar PV and CCS applied to the entire energy generation capacity. This reduced BAU CO₂ emissions from 259 MtCO₂ in LG to 6, saving 253 MtCO₂, and from 292 MtCO₂ in ML to 7, saving 285 MtCO₂, and from 630 MtCO₂ in HG to 14, saving 616 MtCO₂. This scenario exhibited the maximum CO₂ emissions savings from all scenarios, saving between 253 to 616 MtCO₂ and although it might be technically feasible in the future, it remains very challenging if not impossible to meet 90% of power generation via Solar PV and also equally challenging to apply CCS on all existing and new power plants, hence, the scenario is neither currently technically feasible nor is it economically viable and therefore not a plausible solution.

Row 6. Energy mix was maintained from the previous scenario at 90% Solar PV and 10% fossil fuels with CCS, this time applied to new energy generation capacity only. This reduced BAU CO₂ emissions from 259 MtCO₂ in LG to 120, saving 139 MtCO₂, and from 292 MtCO₂ in ML to 125, saving 167 MtCO₂ and from 630 MtCO₂ in HG to 137, saving 493 MtCO₂. This scenario although more realistic than the previous one, as it keeps existing power plants the same with no

cleaner energy mechanism and only adds that to new energy generation, it follows on from the previous scenario, and also does not seem feasible since it is challenging to generate as much as 90% from Solar PV.

Considering the six scenarios presented here, it gives a clear idea of how the inherent advantages of CCS and Solar PV translate into CO₂ savings. However, considering the plausibility of these options, it seems that Row 4 of the Most Likely Growth scenario emerges as a most technically feasible, economically viable and therefore a most plausible solution.

Growth rates

One could question why LG and ML cases are relatively close to each other as compared to HG, as explained earlier, the forecast figures in this study are based on a government commissioned study by ECRA and is therefore subject to their assumptions. This, however, could be avoided if it was to be created from scratch using data from international sources and applying different assumptions. Following the report, the ML is the most likely case in this study as well, however, it was important to include LG and HG to give a range of flexibility for the forecast of energy use in Saudi Arabia.

Sensitivity analysis

- Carbon emissions factor used in the current study is Saudi Arabia's figure from 1999-2002 (EIA 2007), which may have changed over the last 8 years and would change the factor used. A study on Saudi Arabian power plants by Alnatheer (2002, 2006) assumed carbon emission factor of 0.647 tCO₂/MWh, which is lower than that of 0.816 tCO₂/MWh assumed in this paper. Therefore, although the difference in factors suggests that the figures are not accurate but for the sake of caution the latter has been used.
 - o Using 0.647 tCO₂/MWh instead of 0.816 tCO₂/MWh assumed in this paper, makes the following changes:

Equation 7: Calculating the new values for X_{CR} and X_{NG} :

$$\begin{aligned}
 X &= 0.48X_{CR} + 0.52X_{NG} \\
 647 &= 0.48X_{CR} + 0.52X_{CR} \cdot 0.77 \\
 X_{CR} &= \frac{647}{0.52 \cdot 0.77 + 0.48} \\
 X_{CR} &= \frac{647}{.88} \\
 X_{CR} &= 735 \\
 X_{NG} &= 566
 \end{aligned}$$

- For Case 4, applying equation 5 makes the following changes:

Equation 8: Calculating CO₂ Emission Reduction Rate at New Energy Mix at 10% Solar and 90% CCS using 0.647 tCO₂/MWh

$$\begin{aligned}
 Y &= 0.2(0.432X_{CR}) + 0.3(0.468X_{NG}) + 0.05(0.1_{XS}) \\
 Y &= 0.2(0.432 \cdot 735) + 0.3(0.468 \cdot 566) + 0.05(0.1 \cdot 56) \\
 Y &= 0.2(317) + 0.3(265) + 0.05(5.6) \\
 Y &= 63 + 79 + 0.28 \\
 Y &= 142 \text{ kgCO}_2 / \text{MWh} \\
 Y &= 0.142 \text{ tCO}_2 / \text{MWh}
 \end{aligned}$$

- Therefore, for Row 4 using Energy Mix at 10% Solar and 90% CCS using 0.647 tCO₂/MWh emission factor for the Most Likely Growth Case changes to: **142** MtCO₂ instead of 146 MtCO₂ saving 150 MtCO₂.
- In the current study, the energy mix is based on 2007, using slightly more natural gas (52%), this has already changed in the following year in 2008 (45% NG) and might continue to change. This energy mix was also assumed constant for the entire duration of the study (up to 2025), this is indeed hypothetical since the actual future energy mix might be different and therefore it is not an accurate reflection of the level of CO₂ emissions. However, the study provides a guide only rather than accurate figures, and therefore, it should not interfere with the outcome and conclusions.
 - Energy mix for this study also assumed two types: crude oil and natural gas, grouping heavy fuel and diesel with crude oil.

- The carbon emission reduction rate of CCS system is dependant greatly on the energy mix, for example, CR-CCS reduction rate is 80% and NG-CCS reduction rate is 70%, total carbon dioxide emission reduction is calculated based on how much CR and NG is used in the energy mix, whereas Solar PV reduces business-as-usual by 95%.
 - Using a different CCS reduction rate for the energy mix of 45% NG and 55% CR, presents the following changes:

Equation 8: Calculating CO₂ Emission Reduction Rate at New Energy Mix at 10% Solar and 90% CCS of which 55% is CR and 45% is NG

$$\begin{aligned}
 Y &= 0.2(0.455X_{CR}) + 0.3(0.445X_{NG}) + 0.05(0.1X_{PV}) \\
 Y &= 0.2(0.455 \cdot 927) + 0.3(0.445 \cdot 714) + 0.05(0.1 \cdot 56) \\
 Y &= 0.2(422) + 0.3(318) + 0.05(5.6) \\
 Y &= 84 + 95 + 0.28 \\
 Y &= 179 \text{ kgCO}_2 / \text{MWh} \\
 Y &= 0.179 \text{ tCO}_2 / \text{MWh}
 \end{aligned}$$

- The emission factor has been slightly reduced from 180 to 179, but the Case 4 ML figure is the same when rounded up, **146 MtCO₂**, the full figure without rounding is now **146,065,510** instead of **146,197,676 tCO₂**.

Discussion on CCS and PV LCA studies

- All of the findings by the 40 LCA studies conducted are themselves based on different system boundaries and different sets of assumptions which change their findings accordingly. However, the average figure of these findings for CO₂ emission reduction has been used in the current study and is by itself not exact yet reliable enough to generate general findings. CCS studies for example have been based on either hypothetical or pilot projects that are non-existent, this reality adds a factor of variability to the general findings of these studies, and therefore, the current study.
- The restriction of the findings to a different context challenge the current study. For example, CCS studies are based on coal power

generation and natural gas, with none on crude oil, and since in terms of carbon content, crude oil is between coal and natural gas, the study adopted an assumption of an intermediate figure for carbon emission reductions.

- Risk of CO₂ leakage from CCS, although quantified in a number of studies, remain hypothetical or based on a pilot scale. Also, because the CCS process creates more CO₂ than there otherwise would be, it is not truly sustainable. These factors although mentioned by some, are not taken into consideration quantitatively in individual studies. The extra CO₂ created in the atmosphere is as much as one-fifth (100 gCO₂/kWh out of 500 gCO₂/kWh, approximately) of the total generated (see Figure 6-9).
- There are also many different technologies considered under CCS and PV, and individual findings therefore vary accordingly. The average based on 20 LCA studies for each, CCS and Solar PV, should give a reliable indicator for the current study, however, for the sake of sensitivity such variations should be acknowledged.

Other environmental consideration

- The focus of the current study has been on climate change (i.e. considering the indicators global warming potential, CO₂-equivalent and/or CO₂ emissions), this has been the definition of the term 'environmental impact,' although the environment effect encompasses much more than climate change when considering other indicators.
- Some cited studies considered other emissions, which were not taken into account in this study. These present findings show climate change as an environmental indicator as the only beneficiary from CCS as compared with other impacts. The following impacts show a worsening situation after applying CCS, the direct impact³³ of CCS as reported by Singh et al. (2010) report:
 - Acidification, up by 58%

³³ Direct impact are described as "the impact due to emission of pollutants to air from combustion and capture processes at the power plant facility" (Singh et al. 2010).

- Marine eutrophication, up by 21%
- Photochemical oxidant formation, up by 11%
- Particulate matter formation, up by 13%
- Human toxicity, up by 29%
- Terrestrial ecotoxicity, up by 434%
- Freshwater ecotoxicity, up by 961%
- Marine ecotoxicity, up by 23%
- Viebahn et al (2007) report:
 - Photo-oxidant formation, up by 96%
 - Eutrophication, up by 44%
 - Acidification, up by 39%
 - Health impact, PM10-equivalents, up by 38%
 - Cumulative Energy Demand (CED), up by 34%
- Benetto et al (2004) report:
 - Human health, up by 95%
 - Ecosystem quality, up by 40%
 - Resources, up by 60%

These are large impacts that are not reported in this study, or others that assumes a climate change focus, but are considered as harmful to the environment, especially when changes reported are as high as 400% and 900% for ecotoxicity. Such figures do not reflect adherence to a sustainable future.

- CCS systems also may cause structural changes induced by underground storage of CO₂, causing changes in the geological formation as well as thermodynamic properties, increasing the risk of micro-seismic³⁴ activity, possible earthquakes and soil collapse.

Energy efficiency

Energy efficiency losses are not assessed for this study for the sake of simplicity. However, energy efficiency of approximately 30% is usually considered when adding cleaner energy measures to the electricity sector.

The equations generated for this study are not context-specific and could be applied to different studies:

- Equation 1. Calculating energy, peak load, and mean load
- Equation 2. Calculating carbon dioxide emissions

³⁴ Micro-seismic is a geomechanical deformation induced by injection

Equation 3. Calculating the CCS energy mix carbon reduced emission rate

Equation 4. Calculating total electricity emissions of CO₂ with CCS production to new power plants only

Equation 5. Solar and CCS energy mix CO₂ emission reduction rate

Moreover, because the future cannot be forecasted with certainty, such a predictive study has a risk of inaccuracy - the results are subject to the assumptions. In the current study general equations have been derived that could be used to create pathways to cleaner energy. These equations are dependent on input values, derived from other studies. Growth rates of energy use, for example, could be derived from international institutions with reliable sources (BP, World Bank, EIA) or as in this case from internal governmental sources (ECRA).

The results presented in this study show the savings in CO₂ emissions that could be generated if Saudi Arabia opted for applying such cleaner energy measures as assessed, in its electricity sector. These transition paths provided energy mixes between fossil fuels, CCS and Solar PV for power generations.

The subject of energy is highly interlinked with dynamics of the international oil market, which in turn is ruled by changes at the global level of politics, the environment, technology and economic development of countries. The estimation of energy use in the future is predictive; such findings in the current study do not determine future trends but rather provide general scenarios of what the pursuit of cleaner energy in Saudi Arabia might achieve, with the hope that this might advise 'green policy' in Saudi Arabia.

The current state of the electricity supply sector in Saudi Arabia suggests that little has been implemented yet in terms of developing sustainability transitions, especially in making significant investment in CCS and Solar PV. As the rest of the world advances in these key energy technologies, there is an opportunity for Saudi Arabia to participate in technology research and development to maintain itself as a world energy leader.

Unlike those in the oil and gas industry, Solar PV is an innovation-intensive technology that requires constant technological advances to be made by

cumulative competences that should start now. Similarly, CCS technologies are in the pilot scale with potential for development and room for advancements.

Given the opportunity discussed in this paper, Saudi Arabia is recommended to consider the possibility of decarbonising fossil fuels by applying CCS and utilising direct sunlight by Solar PV, namely, Row 4 in ML.

In conclusion, this chapter has provided scenarios for Saudi Arabia that could provide an assessment for policymakers in terms of how CCS and Solar PV could provide CO₂ emissions savings possible to be achieved in the Kingdom, and therefore, provides insight for decisions about investment in advancements and innovations in renewable and sustainable energy technologies.

7 Materializing The Saudi ‘National System of Innovation’: Reporting Results from Interviews

This chapter forms the second part of the findings, it employs a qualitative inquiry and reports the results of thirty interviews conducted with individuals from across the Saudi economy to inform the materialisation of the Saudi ‘national system of innovation’. In the introduction to the chapter, a brief summary of the objectives of the research interviews is provided, an explanation on the use of methodology and strategy of data collection, and participants. The results of the interviews are then presented as: 7.2. Identifying major forces in the Saudi economy, 7.3. Understanding the relationships and inter-linkages, 7.4 knowledge and learning, 7.5. Environmental sustainability direction, and 7.6. Summarizing contributions.

Chapter Content

7 Materializing The Saudi ‘National System of Innovation’: Reporting Results from Interviews

- 7.1 Introduction
- 7.2 Identifying Major Forces
- 7.3 Understanding the relationships and inter-linkages
- 7.4 Knowledge and Learning
- 7.5 Environmental Sustainability Direction
- 7.6 Summarizing Contributions

7.1 Introduction

This chapter reports the results of the research interviews conducted for the *purpose* of assisting in answering the dissertation's research question, in particular the objective of the research interviews is to inform the *materialisation* of the 'national system of innovation' (NSI) for Saudi Arabia.

For this chapter, the chosen *methodology* is a qualitative case study to explore the country case of Saudi Arabia; both the findings from this chapter (qualitative) as well as the previous one (quantitative) will be incorporated to construct cleaner energy transition and sustainability pathways for Saudi Arabia in the final chapter. The data collection method used is semi-structured in-depth interviews with open-ended questions. A set of questions was compiled³⁵ and a degree of flexibility was given to maximize information gathering from interviewees, including customised questions for each interviewee depending upon their individual activities (publications, statements, nature of work) related to the research questions. The selection of the interviewees has been based upon their knowledge, experience and influence with regards to the areas of the interview question, namely, the Saudi economy, science, technology and innovation activities, and carbon management activities.

There are thirty *participants* (P) in the research interviews who are individuals from *agents*³⁶ across the Saudi economy – with a particular focus given to technological innovations, cleaner energy and sustainability efforts – these include policymakers, key researchers, academics, government officials, CEOs and managers of key organizations as well as experts and practitioners in their fields. All interviews have been conducted over the period November 2008 to February 2009. Table 7-1 shows information on interviewees, most of the participants are PhD holders (24 participants), and most were Saudi

35 For a sample of interview questions see Appendix A7.1

36 Borrowing terms from the NSI framework, 'agents' are actors that constitute the NSI (see chapter 4)

nationals, many are either former or current directors / CEO of companies, centres, and/or institutes covering industrial pillars (7 participants), government agencies (9 participants), research centres (5 participants), and academic institutes (8 participants). One of the participants is from the royal family, and at least three of the participants are involved in the newly created team for working on the Saudi National Innovation Eco-System.

Table 7-1 Information on Interviewees

<i>Category</i>	<i>Variable</i>	<i>No. of interviewees</i>
Nationality	Saudi	28
	Non-Saudi	2
Main affiliation	Industrial Pillars	7
	Government Agencies	9
	Research Centres	5
	Academic Institutes	8
Highest academic qualification	Doctoral Degree	24
	Master Degree	1
	Bachelor Degree	5
Type of Interview	Telephone / Recorded	28
	Face-to-Face	2

The identity of participants is kept anonymous using letter P followed by a number to indicate participants e.g. P1, P2, ...etc throughout the chapter, an informed consent from the participants has been granted prior to the interview, and therefore, it satisfies the ethics and principles of research procedures. There were eleven potential interviewees that did not respond and three that rejected to participate in the research. The majority of the interviews have been conducted over the phone with some face-to-face interview meetings and others through emails. This was decided upon based

on the preference of each interviewee, other factors taken into consideration included practicality, geographical location and cultural aspects³⁷.

The interview results are designed and analysed in light of the previous chapters and based on the research questions, the literature review as well as the conceptual and theoretical frameworks which have guided the research interviews from writing the questions, to the conduction of the interview as well as analysing and identifying results. This chapter will provide a thorough articulation of the empirical findings emerging from the investigated research, presented as follows: 7.2. Identifying major forces in the Saudi economy, 7.3. Understanding the relationships and inter-linkages, 7.4 knowledge and learning, 7.5. Environment sustainability direction, and 7.6. Summarizing contributions.

7.2 Identifying Major Forces

The first focus of the investigation is to identify the major forces in the Saudi economy that will constitute *agents* of the Saudi NSI. These include (7.2.1) government agencies, (7.2.2) industrial pillars, (7.2.3) research centres, (7.2.4) academic institutions; each will include lists of agents by order of influence – the lists are compiled after considering results from interviews based on a points system³⁸.

7.2.1 Government agencies

The following is the list of government agencies from the results ranked by order of influence:

³⁷ Part of the Saudi culture dictates the separation between genders and therefore many endorse that view and prefer to speak through the phone rather than meeting face-to-face.

³⁸ Each of the thirty interviews have listed the agents of Saudi NSI under each group, all of which have been included; each agent has been assigned a point corresponding to where it was placed by how many participants, the agent that received most points is placed at the top in that group to indicate power of influence. [See Appendix A7.2](#)

1. Saudi Arabian General Investment Authority (SAGIA)

SAGIA is a government agency that operates in key sectors: energy, transport and logistics, ICT, health, life sciences and education; its vision is to "act as a gateway to investment in Saudi Arabia" through attracting FDI.

Placed at the top of the list by most participants, SAGIA's main role involves the attraction of investment from within the economy and mostly from abroad. Its establishment was for that prime objective of stimulating economic diversification in the Kingdom. All participants seem to agree that SAGIA is the first government agency ranked highest in its influence to economic development in Saudi Arabia.

Furthermore, SAGIA has been very active towards economic development in Saudi Arabia. Its main achievement has been the progression of its 10x10 Program, which is to place the Kingdom of Saudi Arabia (KSA) in the top 10 countries for ease-of-doing-business. For the achievement of this objective, SAGIA has hired Stanford Research Institute (SRI) to identify areas of improvements within the Saudi economy (P7, P18, and P15).

In 2004, P18 explains, the World Bank has ranked Saudi Arabia as 94 amongst the world for ease-of-doing-business; SAGIA took it upon itself to work on each of the key performance indicators (KPI), with the help of an external consultancy group to raise the ranking. He explains that SAGIA has classified them by cost and impact, long-term changes, mid-term changes, and difficulty of achievement, this was then effectively communicated as a collective goal to all ministries so as to work towards it. In 2005, the ranking has progressed to 68 and subsequently in 2006 a great leap of progression pushed the ranking up to 38, progress continued in 2007 to reach 23, this has exceeded the team's expectation of reaching 30 or 29, P18 continues to explain. In 2008, the rank recorded an outstanding 16, and thereby setting the scene for the Kingdom to meet its target of being on the top ten most attractive countries in doing business by 2010. *"The mere success of their*

10x10 program has produced a sense of hope for government entities,” P15 says, a former director in SAGIA.

P18, then director of ICT at SAGIA, explains that SAGIA started as a research centre for the purpose of making the economy “healthier”; it has focused on national competitiveness and established economic cities. It has also facilitated FDI to invite international investors in all sectors and established communication channels. He believes that SAGIA has succeeded in improving the image of Saudi Arabia in international business. ‘First stop’, one of SAGIA’s services which offers processing business transactions in a single stop, is the gate to businesses in Saudi Arabia, SAGIA played a proactive role in its contribution to the Saudi economy.

One of the main factors of its direction is driven by the lack of technical expertise in the Saudi market and especially the lack of a Saudi intellectual capital, SAGIA therefore concluded that the first step to achieve that is via attracting investment from abroad, not for the sole purpose of generating money, but also for knowledge enrichment, explains P18.

Moreover, P18 notes that Saudi Arabia was the largest recipient of FDI in the Arab world in 2006, attracting \$18 [£11] billion, an increase of %51 over 2005, according to a report by the United Nations conference on trade and development (UNCTAD). In addition, P18 explains that in their 10x10 vision they have learned from the Malaysian ‘2020 vision’ experience, he believes with the success of the 10x10 programme, SAGIA has directly positively impacted economic development in the Kingdom.

“SAGIA invites outside investors to the country and that is what really drives economic development” says P7. Also, P5 believes that it plays a great role in directing investment in the industry.

Moreover, P3 believes that SAGIA’s contribution to economic development is not less than any other ministry, also, P23 explains the effectiveness of SAGIA’s efforts in using international benchmarking to facilitate investment is

better than those efforts by the ministry of economy and planning and ministry of finance.

2. Ministry of Economy and Planning (MEP)

MEP was established in 1970 when the formal planning of the Kingdom has started. It produces five-year plans and has a statistics department which publishes periodic reports providing extensive data about Saudi Arabia's economic indicators.

P7 has positioned MEP amongst government agencies with direct contribution to the Saudi economy, he adds “*despite the fact that the ministry of finance is doing all the job*”. Some argue that MEP does not generate real work. Instead, “*it gathers data and aspirations from different ministries and puts them together in a form of a plan*”, P26 says, he also criticises MEP’s statistics department that results, which are published, are based on inaccurate data.

Although placed second in influence, most participants seem to believe that MEP has many weaknesses that present its role as ineffective. One of the participants criticises the lack of planning in expanding cities, the infrastructure of Jeddah city is one of the examples given by P24, the lack of proper planning and forecast study resulted in the chaotic infrastructure in the city, and the exploding population in Jeddah has resulted in the overpopulation of the city.

3. Ministry of Commerce and Industry (MOCI)

MOCI is responsible for the commercial and industrial activities in the Kingdom and is the authority for ensuring WTO compliance and has chambers of commerce and industry across all regions in the Kingdom.

P15, a former director in a government institution argues that the MOCI lacks the proper infrastructure and clear strategy. Although they are working on minimizing the reliance of Saudi Arabia on the oil sector, and they are aware of their position, however, they lack skilled labour. It is one the vital entities that should play an instrumental role in pursuing economic diversification.

SABIC, a world's leading petrochemical company, reports to MOCI, P13 explains.

4. Ministry of Finance (MOF)

Established in 1927, MOF is responsible for the government's fiscal and monetary policy, supervising government's accounts and expenditures, as well as monitoring the implementation of government policies for providing loans to individuals and national corporations for various development activities through banks and funds; these include: agricultural bank, credit bank, industrial development fund (IDF), real estate development fund and public investment fund.

P3 believes MOF is one of two main government agencies that contribute to economic development, the second one being SAGIA; MOF was ranked second by P13 in influence to the economy; P7 also believes that MOF is undertaking a tremendous role, it has established a number of initiatives that contribute to economic development and could form basis for the NSI such as IDF, this was also communicated by other participants. *IDF was created to stimulate industrial projects, it provides financial assistance in the form of short-term loans to investors in industry. It offers technical, administrative, financial and marketing advice.* P5 also believes Saudi IDF did a great job in creating and funding industrial project in the sector.

5. Supreme Economic Council (SEC)

Chaired by the king, members of SEC include ministers and the minister of state. Its role is to create economic policies and manage economic affairs, among other things.

P13, a consultant to MoPM and a formal representative of Saudi Arabia in various international environmental meetings, and P18, a director at SAGIA both believe that SEC is the highest rank of government agencies in its influence and contribution to economic development. SEC brings ministries together for the objective of developing the economy.

However, P23, an advisor to the Ministry of Water and Electricity, believes that even though SEC was established for the sole purpose of driving economic development, it has failed to plan for it properly. He believes that in its 10-years existence it has not accomplished much.

On the other hand, P15, a former director in a public institution, argues that SEC is an important council to be positioned high in government agencies because its main role is to review and approve economic policies. It has in fact been established for the objective of driving economic development. They also act like the umbrella that brings together different ministries on the same table to discuss issues relating to advancing economic development in the country. On the other hand, P11 is not sure about SEC's contribution to the Saudi economy, *"I don't know what they have done to the economy"*.

P7 who ranked SEC the first in its contribution to economic development says that SEC's contribution to economic development comes in many aspects, it sets the rules and regulations and ultimately shapes the direction of the Saudi economy. P4 also reaffirms this point by saying that *"SEC sets the main strategic economic plans for the Kingdom"*.

P13 argues that SEC is a unifying and coordinating body that should take a more active role in facilitating the interaction between government, industry and academia and should stimulate the development of institutions that aim to play a major role in economic development *"SEC has the opportunity to coordinate that"* he says.

6. Ministry of Petroleum and Mineral Resources (MoPMR)

MoPMR was established in 1960 to execute oil (gas and minerals) policy. It supervises its affiliate companies for observing and monitoring exploration, development, production, refining, transportation, distribution activities related to petroleum and minerals products. It monitors companies: Saudi Aramco, Saudi Texaco, Aramco Gulf Operation Ltd and Saudi Arabian Mining Company (Ma'aden) and oversees the Saudi geological survey (SGS).

P11 believes MoPMR has taken a key leadership position in driving economic development in Saudi Arabia. He also believes that MoPMR is carrying out activities that really should be done by other ministries. For example, the cluster initiative is an effort by MoPMR when in fact it should be by MOCI; the utilisation of gas, ethane and its distribution for economic development; and also forcing and encouraging petrochemical companies to go to a third level of industrialisation, as well as the establishment of industrial parks (3rd and 4th level of industrialisation) – all these have been driven by the governor of gas under the MoPMR. P18 also believes that MoPMR is the driving power of economic development, which embraces Saudi Aramco and Maaden, two industrial pillars, amongst other organizations.

7. Ministry of Labour (MOL)

MOL is responsible for securing jobs for citizens, recently it has launched 'Nitaqat' a nationalisation / Saudisation effort to increase the percentage of Saudi labour and deal with challenges facing the labour market.

MOL is placed 7th by participants and is believed that it shapes policy with regards to human resources, particularly to deal with the great challenge of unemployment that Saudi Arabia faces.

8. Ministry of Higher Education (MOHE)

MOHE was established in 1975 and has undergone enormous reform efforts over the decades. Most recently, it has launched transformative efforts to upgrade the education system in the Kingdom, some examples: national centre for assessment in higher education, national commission for academic accreditation and assessment and national centre for e-learning and distance learning.

P7 believes that MoHE's contribution to economic development is very limited: *"Since you cannot have economic development if you don't have a good education system".* There are of course scholarship programmes and universities that are managed by MoHE and are expected to contribute to raising the national standard to fit better employment and contribute to economic development.

9. Saudi Arabian Monetary Agency (SAMA)

Established in 1952, SAMA is the central bank of the Kingdom that supervises commercial banks and manages the country's financial system.

SAMA is placed 9th in contributions of government agencies to economic development and Saudis' NSI. It is a regulatory institution that oversees commercial banks and the financial system and therefore acts as a 'supporting' actor in the NSI.

Capital Market Authority (CMA)

CMA is a government entity that was established under the Capital Market Law in 2003 to supervise and control the Saudi capital market. Its role include regulating the market, protecting investors, monitor business activities, provide information to the general public.

10. The Royal Commission of Jubail and Yanbu (RCJY)³⁹

RCJY was established in 1975 as an autonomous organization that works in petrochemicals and energy industrial cities. It succeeded in creating the industrial cities of Jubail in the East and Yanbu in the West of the Kingdom. The overall development of Jubail and Yanbu accomplished with an investment of SR 84 [£14] billion has witnessed the creation of over 233 industries that have invested over SR 244 [£40] billion, providing employment for over 107,000 workers. The 154,000 residents of the two cities enjoy world-class amenities and security.

Participants placed RCJY as the 10th agent under government agencies, RCJY is regarded as a contributor to economic development and the infrastructure of industrial activities. The success of the oil industry in the East region is partially accredited to RCJY who built the industrial city of Jubail.

P15, a former director in a public institution suggests that this commission has been one of the industrial pillars in the Saudi economy. It was established by

³⁹ Source: RCJY Website <http://www.rcjy.gov.sa/en-US/aboutrcj/Pages/default.aspx>

a royal decree and its role involved the creation of the two industrial cities of Jubail and Yanbu, which were regarded as state of art Saudi cities. However, today its mandate is expanding beyond that. The former director argues that because they started as a royal commission, the King has been the head of the commission and therefore the commission benefited from the full financial support of the King. In addition, P7 also believes that the commission contributes significantly to the economy.

11. Ministry of Interior (MOI)

MOI works towards achieving security and stability in the Kingdom, its role is to fight crime, terrorism and drug smuggling and reinforce security cooperation with Arab and regional countries.

MOI influence the process of economic development in the country via its regulations, such as its regulations towards the ministry of labour, its regulation towards immigration and handling the foreign workforce. These ultimately shape the way the population participates in economic development. It was placed 11th by participants.

12. Ministry of Water and Electricity (MOWE)

MOWE is responsible for the development and planning of all water and electricity projects in the Kingdom.

MOWE is the authority in the electricity sector and provides a platform for interlinkages between different players in the sector. It is placed last by participants in government agencies.

Other agents that were suggested by some participants are not included as part of the NSI agents due to their broad role and indirect influence to the innovative capacity. These include the **Ministry of Justice (MJ)**, which *administer Sharia law and the judicial system in the Kingdom* only recommended by P18. In their efforts to reform the judicial system for handling disputes and administer Sharia Law and the provision of legal services for all Saudi citizens. **Ministry of Transport (MOT)** *is responsible for*

road and transport management in the Kingdom as well as a geographical information system that is under development. The MOT is responsible for the creation and management of the road network, and other transport networks (sea and air). Such components are critical for economic development of the country, the transport system is often used as a benchmark in economic development (P15). P4 puts **Saudi Arabian Monetary Agency (SAMA)** under the government agencies that contribute to economic development through its various economic studies on Saudi Arabia and its publications.

7.2.2 Industrial pillars

Industrial pillars are those activities that ultimately form an ‘industrial base’ in an economy, such activities that are similar in a way to the industrial revolution in Europe and how it spread to America and how it lead their economies into what is regarded today as modern economies. Therefore, an industry is what involves the production and manufacturing. Although similar to business activities, industry is rather different from commerce. Here, results from the interviews are again presented in order of influence to economic development in Saudi Arabia.

P21 starts by saying: *“Industries are secondary, we don’t have a ministry of industry it is joint with commerce”*. P6 also argues that the Kingdom’s utility-based economy focuses on primary resources and export raw materials as they are without a base for the industry. P19 argues that the industrial sector is purely an assembly point of parts and products and machinery that are all imported from abroad. SABIC, one of the major industrial pillars in the country is a transformational production system and not an oil-based industry. Similarly, P14 argues that R&D [in the private sector] is still very weak and is at its early stages, therefore, it is difficult to identify any industrial pillars from the private sector.

According to the participants of the study, the main industrial pillars ranked by their influence towards economic development in Saudi Arabia are the following:

1. The Saudi Basic Industries Corporation (SABIC)

SABIC is the world's largest petrochemical company by market value, SR 1,040,627,644 [£170,218,962]. It operates six strategic business units including Basic Chemicals, Intermediates, Polymers, Specialized Products, Fertilizers, and Metals; SABIC innovative plastics, launched in 2007, leads the plastic industry.

SABIC is mainly driven by joint-venture agreements. Their role is focused on advancing their R&D activities. SABIC is creating industrial partnership across the globe. With their recent acquisition of General Electric Plastics and Holon Research Centre, for example, they are today the number one producer of plastics in the world (P11).

2. The Saudi Arabian Oil Company (Aramco)

Established in 1933 through a concessionary agreement with Standard Oil of California, Aramco is the state-owned national oil company arguably the world's most valuable company with the world's largest oil reserves and production.

Aramco is constantly being invited to participate in economic development in Saudi Arabia, argues P25, this is evident in its involvement with new ideas and transformational products and projects. For example, Aramco is currently managing the King Abdullah University for Science and Technology (KAUST) project (*then in the making*). Aramco is now managing the KAPSARC project, to be launched in 2012.

According to P11, during the past five years, Aramco has taken a very active role in driving economic development in the country. Its role expands beyond the oil industry to include petrochemical complexes. In addition, it is engaged in the country's industrialisation and capitalisation.

P7 claims that together, the oil and petrochemical industries, namely, Saudi Aramco and SABIC, contribute up to 95% of the Saudi economy.

3. Saudi Industrial Property Authority or ‘Modon’

Modon’s role is to create industrial cities and technology zones throughout the Kingdom. Partnering with the private sector, Modon provides services and operate the cities and zones as well as invite investors. Modon is an independent public agency. Part of its mission is to ‘enhance economic activity and industrial competitiveness’ it also focuses on encouraging the participation of the private sector

One of its critics, argues P15, a former director in a public institution, is the ineffectiveness of MOCI which Modon operates under. “*They struggled a lot with the launch of Modon in the last 5-10 years*” he states. The inefficiency of advancing the project in the beginning could provide a challenge for completing it, the allocated money by MOF amounted to SR 10 [£1.7] billion for this organisation.

P12 says “*The industrial platform is expanding*”; he continues to explain that growth is reflected in the number of new industrial companies and projects. For example, Modon has allocated more than a thousand lands for new industrial projects across the country but mainly in Riyadh, Jeddah and mostly Dammam. He further adds that, the government supports industrial companies and give up to 50% of the required capital with almost no interest. In essence, companies could repay over ten years. In addition, such support also involves the exemption of any raw material imported from abroad; There is a 20% off profit taxation levied on FDI, local investments advantages from the no-taxation policy which encourages more industrial projects (P12).

4. Cement Industry

Cement companies⁴⁰ in Saudi Arabia fuel the booming construction in the Kingdom and contributes to its export market.

⁴⁰ There are eight cement companies that constitute the cement industry in the kingdom: Arabian Cement, Eastern Cement, Qassim Cement, Saudi Cement, Yanbu Cement, Yamama Cement, Southern Cement and Tabuk Cement.

There are major activities in the cement industry these include major factories which takes part in the industrial parks in the country, P7 believes that this constitute some degree of technology advance.

5. Economic Cities

The economic cities are all under construction; Part of their mission is to contribute to the Saudi economy and participate in the diversification of the oil-based economy of the country. Economic cities aim for the establishment of new economic, educational and technology hubs in the following economic cities: (1) King Abdullah Economic City in Rabigh, (2) Knowledge Economic City in Al Madina Al Munawara, (3) Jazan Economic City and (4) Prince Abdul Aziz bin Mousaed Economic City. In 2006, Emaar [literally, the construction and development of] the economic city (EC), was created as a joint venture between Emaar Properties, a UAE-based construction company and Saudi Arabian investors with a starting capital of SR 300 bn to create King Abdullah Economic City (KAEC), the first project undertaken and is at near-completion phase.

P7 believes that economic cities will take years to come, he explains that people still don't understand the concept of economic cities, and although there are some prospective industrial parks, he says: "I don't think it will contribute yet in the coming 5-10 years".

P23 believes that the economic cities are in their 'dying' stage, this he argues is due to the global economic meltdown [of 2008]. However, he believes that the closest to surviving is the King Abdullah Economic City (KAEC).

6. Saudi Electricity Company (SECO)

SECO is the electricity company which dominates the electricity sector in the Kingdom, it is 80% state-owned.

Participants placed SECO sixth in industrial pillars and believe it contributes to Saudi's NSI in being a main electricity provider.

7. Ma'aden:

Arabian Mining Company (Ma'aden)

New in business and manages two major projects that are under construction. Maadin is expected to become the third major industrial pillar and a key player in the Saudi economy after Saudi Aramco and SABIC (P15).

8. The Saudi Clusters Programme (Clusters)

Clusters is a government-led initiative that work on automotive, construction, metals processing, plastic packaging and consumer appliances.

Participants placed Clusters in the 8th place in industrial pillars, although a new initiative, there is a high potential in its contribution to Saudi's NSI.

9. The National Industrialization Company (Tasnee)

Established in 1985, Tasnee is the first joint-stock private industrial company. Its products range cover petrochemical, chemical metal and diversified products and services, it aims is to contribute in the diversification effort of the Kingdom; Tasnee is the world's second largest titanium dioxide producer.

P15 explain that Tasnee is a new business in the petrochemical industry, they specialise in upstream and downstream petrochemical with very diversified portfolio of activities focusing on industries in Jazan. "They are potentially big players" in contributing to Saudi's economy [and NSI], says P15.

10. Chambers of Commerce and Industry (CCI)

CCI is an initiative that started in Jeddah (JCCI) in 1946 and eventually 28 chambers were established across the regions of the Kingdom. It provides services to the business sector, stimulate small- and medium- sized enterprises (SME) sector and acts like the hub between that and the government. It also participates in national development programmes such as 'Saudization' of the labour force, amongst others.

Participants placed CCI as 10th in industrial pillars, they believe it contributes in shaping the Saudi economy, P21, a senior at JCCI [at the time of the

interview], explains that like other chambers, JCCI is a lobbying body and acts like an NGO with no power. There are 21 chambers of commerce in Saudi Arabia and they all operate under the Council of Chambers which is located in the capital, Riyadh. The first chamber of commerce was established in Jeddah in 1946, that was even before a ministry of commerce or trade ever existed; the chairman of JCCI formed MOCI afterwards. The main chambers in Saudi are in the three main areas of most populated cities, Riyadh, Jeddah and Dammam.

“They have done a great job since their inception” says P7. He critically assesses it explaining that in the past, there was much more enthusiasm and professional calibres and the chambers did an outstanding job, however, today and especially in the last two years, the members lack experience and drive as it is becoming more personalised, *“more like a ‘club’ for businessmen in the country, just to become a ‘member’ but not to add any significance. It is a façade for businessmen”* he states. However, he explains that they still do organise a lot of forums and conferences especially with international collaborations and it is one of their esteemed contributions. For example, The Exhibition Centre demonstrates market demand, places are booked sometimes two years ahead of time. *“If you want to book a place for today, there are no places up until 2010 in Riyadh Chamber of Commerce”* P7 explains. Another impediment is the ‘competitive’ nature of the members and their lack of collaboration as well as real contribution to knowledge for economic development, P7 adds.

P13 believes that since CCI’s establishment, it has been the representative of the private sector. He argues that they must take a more active role and re-plan their activities because the private sector is heavily reliant on them. He states that government agencies must treat the private sector as a partner rather than a subordinate to whom they dictate regulations. The involvement and participation from the private sector needs to be embraced by the government, he states. He also suggests that the government should facilitate a better cooperation between the private sector and academia.

P21 believes that CCI has succeeded to carry out its role as a *facilitator* between the private sector and the government. For example, JCCI continuously provides a platform to facilitate interaction between members of the government, such as a minister, on one side and business owners and industrialists on the other. *“They come in one table to exchange information such as new regulations by the government, feedback from the business owners and industrialists, updates on how the private sector is doing in general”* P21 explains. The minister usually updates the chamber’s clients (business owners and industrialists) about any new directions set by the government, he then listens to the clients’ demands and feedbacks. *“There is always much anger from the clients side”*, she explains, – therefore, this sort of dialogue is very much needed and relieves a lot of the anger from/to the parties and therefore bridges the gap between them. CCI also works on higher development projects and needs to satisfy both the government and its clients. For example, for the project of developing the cities of Laith and Qunfutha. JCCI must study the area and formulate strategies to facilitate business opportunities via marketing. It has a similar role to SAGIA, P21 argues, but on a smaller scale.

11. King Abdulaziz Centre for Science and Technology (KACST)

KACST is an independent scientific organization regarded as the ‘national science agency’ and ‘national laboratory’ of Saudi Arabia whose functions includes: science and technology policy-making, data collection, funding of external research, and services such as the patent office. The science and technology national policy (STNP) is being formulated by KACST.

KACST was established in 1979⁴¹ explains P16, the vice president, the expectation at that time was that world demands for oil will rise and supply shortages may occur, and as the swing producer, Saudi Arabia might be

⁴¹ The 1979 oil crisis in the USA and the Western world was due to the disruption of the Iranian oil due to the Iranian revolution, which impacted an overall reduction in oil production and oil exports that pushed prices high. It was also at a time of rising nationalism and independence. Thus, KACST was created to advance science and technology, especially in solar energy.

challenged by production, and therefore, the development of solar energy in the Kingdom was important. The first Saudi solar project was launched as a collaboration with USA and another collaboration with Germany, explains P16. Over the decades, the role, structure and scale of KACST has changed with changing priorities as well as technology development, *“the objectives are now different,”* he states, for example he explains that because the production of solar energy has changed, undertaking research in solar is not as expensive as before. *“The use of silicone which was used in electronics is very expensive, the reason why the cost of solar has been expensive, today, thin film technology is used instead to produce solar grade not electronic grade which is cheaper and drive solar costs way down”* he says.

“KACST is like a ministry for science and technology, with its committee headed by the king, so it is even better than a ministry” P16 says, its responsibility encompasses dealing with international agreements and international organisations, it also funds research in universities and is responsible for the national research centres and institutions, explains P16.

12. Petro Rabigh

Petro Rabigh was established as a joint venture agreement by Saudi Aramco and Sumitomo Chemical in 2005 so as to oversee oil refinery and petrochemical of the Rabigh complex. Today, it produces refined petroleum and petrochemical products, using crude oil and ethane as primary feedstock.

Petro Rabigh is regarded as an industrial pillar, placed 11th by participants, as it utilizes hydrocarbons to produce petrochemical products, contributing to the economy of Kingdom.

13. Saudi Iron and Steel Company (Hadeed)

Founded in 1979, the SABIC wholly-owned subsidiary is the largest manufacturer of steel in the Kingdom. Hadeed is located in Jubail industrial city and employs more than 2,800 people. It dominates the iron and steel industry in the Kingdom and also contributes to exports in the global crude steel market.

Participants believed that it contributes to the Kingdom's NSI. Its importance emanate from its role in feeding the construction boom in the country.

14. Saline Water Conversion Corporation (SWCC)

SWCC is a government corporation responsible for desalinating sea-water to augment the supply of potable water to coastal and inland cities across the Kingdom. As the largest electric power producer in the Kingdom SWCC dominates the water desalination in the Kingdom is an important industry that employs latest water technologies to meet rising demands.

Water is very important in the country, due to limited renewable sources for water. SWCC is placed 14th by participants, P7 states: "*we desalinate more than 21% of the world desalination capacity*". This he believes is a competitive area for the Kingdom, "*The war is not going to be in oil but in water*" P7 quotes.

7.2.3. Research Centres

According to the participants, the following is the list of the most influential research centres in the Kingdom by order of influence:

1. King Abdulaziz City for Science and Technology (KACST) R&D Centres

KACST R&D research areas include: water, oil and gas, petrochemicals, nanotechnology, biotechnology, ICT, electronics, communication and photonics, space and aerospace technology, energy, advanced materials, environment and mathematics and physics; Five international scientific journals are being produced with Springer.

Placed first in R&D, KACST is regarded as the national lab that dominates R&D in the Kingdom and therefore one of the foundations of Saudi's NSI.

2. SABIC R&D Centre

SABIC is the Saudi Basic Industries Corporation a world's leading manufacturer of chemicals, fertilizers, plastics and metals; SABIC innovative plastics, launched in 2007, leads the plastic industry.

Placed second by participants, the petrochemical industry is a competitive area for the Kingdom and therefore R&D is very active for supporting and advancing this sector. It is believed to be a key area for Saudi's NSI.

3. KAUST Research Centres

The KAUST Research Centres will focus on: Catalysis, Computational Bioscience Geometric Modelling and Scientific Visualization, Advanced Membranes and Porous Materials, Plant Stress Genomics, Solar and Photovoltaic Engineering Research Centre, Red Sea, Clean Combustion, Water Desalination and Reuse. There are ambitious plans to include a research park, industry collaboration program, innovation cluster, seed fund, entrepreneurial resources, technology transfer and innovation program.

KAUST research centres, although a futuristic undertaking at the time of the interview, has a great potential in contributing to Saudi Arabia's NSI and in leading R&D. Placed third by participants under research centre.

P11 states that KAUST's mission is to develop the economy, he argues: *"the university is very different to anything that has ever existed in Saudi Arabia"*. In the selection of focus areas, P11 explains that there is a rationale behind every institution and that they have all been carefully selected to drive economic development in Saudi Arabia. There are 11 research centres all of which are expected to run in the Fall of 2009, amongst of which are: (1) Solar Energy – This is the first focus area for Saudi Arabia, the plan is to place the country to be a leading exporter for solar cells to Europe; (2) Water Desalination – this is a focus area because it is a number 1 threat in Saudi Arabia due to the high costs of the use of current technology for water desalination. *"We're amongst the world's top water desalination and plan to develop the technology further to remain as leaders in the field"*; In addition, P11 adds *"another area where the Kingdom wishes to excel in is the*

development of 'catalysis' for refining the petrochemical reaction at the lowest cost possible". More importantly, he argues, there are strategies for technology and knowledge transfer within KAUST and from KAUST to different entities across Saudi Arabia, the international collaboration factor in KAUST will always exist, the aim is to be perceived by the world as an international university.

4. Aramco R&D Centres

Aramco has two major centres for R&D, (1) Research and Development Centre pioneering researching latest technologies to improve operational reliability, efficiency and safety; (2) The advanced research centre for exploration and petroleum engineering centre which leads research in upstream activities.

Placed fourth under R&D centres in the Kingdom, Aramco's R&D centres lead technological innovation in the oil industry. It is one of the earliest R&D activities in the Kingdom, but faces the challenge of transferring that knowledge and technological competitiveness across the Kingdom.

5. KFUPM applied research centre

KFUPM has a number of centres that aim to build a strong collaboration between university and industry focused on R&D in science, technology and innovation. (1) King Abdullah Science Park, established in 2002, it houses firms involved in the petroleum and chemical industry and the IT sector, for example: Schlumberger and Yokogawa.

KFUPM R&D centres and initiatives are placed fifth by participant as they form a key foundation for the Saudi NSI by forming strong inter-linkages between (KFUPM) university and the industry in the oil and gas and energy sectors. P6 explains that research centres within KFUPM started in 1977 and perhaps was amongst the first in the Kingdom, he adds that they started with five-years research plans and worked their way until they have become self-reliant in terms of finance with the university paying researchers salaries only, they carry out consulting work for organizations across the Kingdom especially for the oil industry.

P6 describes the research innovation office within KFUPM as one that takes care of quality control of projects and reports and also deals with intellectual property contract and patent office – thus, providing a platform for innovators, lawyers, consultants and participants through seminars as well service offices.

6. Mawhiba

Mawhiba [Talent in Arabic] is an NGO and non-profit foundation established to foster giftedness and creativity in students from pre-school to university with the aim of upgrading the skills of Saudi nationals to improve their employability and balance the Saudi labour market.

Participants placed it sixth, Mawhiba works with local as well as international partners to pursue its objective. P4 explains that Mawhiba is an innovation endeavour that aims to stimulate ideas, inventions and innovations. One of its programmes involves a web-based service that is open to the public, electronically collecting ideas via submitting it to a panel of experts to assess its investment prospective as a patented innovation. For example, one of the ideas submitted was related to the telecom industry and the idea was further developed into a registered patent. The inventor was given a chance to present in the Ibtikar [literally, creativity] Exhibition organized by Mawhiba, his invention was commercialised in the market. Another example of an idea is one that was related to maintaining the wakefulness of a driver in a car, the idea was translated into a registered patent and the Saudi inventor was invited by Mawhiba to present in an exhibition in China, there he signed two contracts with two Chinese companies to commercialise his invention. P4 adds that Mawhiba provides awards to motivate young inventors, for example the annual award Mawhiba Science Creativity Award presented to the best invention.

Mawhiba's organisational structure start at the president who is the king himself, the board of trustees is composed of princes, ministers, businessmen, and specialists. These people set the direction and the strategic objectives for the foundation. A foreign consultant (McKinsey) has

been invited to participate in drafting the vision, mission and objectives of the foundation.

There is a patent office in Saudi Arabia at KACST, says P4. There is a recent programme that Mawhiba has developed, which is The 60 Patent Programme which as the name suggests aims to register 60 patents. So far, there are 20 patents that have been registered. Mawhiba is further marketing for this to attract more and more inventions, the service that Mawhiba offers is that they register the patent on the inventor's behalf through KACST Patent Office, therefore, the inventor brings the idea and register it free of charge.

7. King Faisal specialist hospital and research centre (KFSHRC)

Established more than 30 years ago, KFSHRC forms a key R&D activity in the healthcare sector in the Kingdom. It provides the highest level of specialized R&D and an integrated education and research setting.

Participants placed KFSHRC and the healthcare sector in the 7th place and believe that it contributes to the innovative capacity in the Kingdom. Other national hospitals include: the National Guard hospital, King Fahd Armed Forces Hospital, together they make the leading public hospitals in the Kingdom that bring cutting-edge technologies to the healthcare sector. The private sector is emerging in the healthcare sector, an example is The International Medical Centre (IMC).

8. Centre Saline Water Desalination Research Institute (SWDRI)

SWDRI is SWCC research institute to develop research in saline water desalination technologies and aims amongst other objectives to promote scientific and technical capabilities through cooperation with national and international research institute in areas that include: chemistry, corrosion, ecology and marine, reverse osmosis, and thermal research.

In the eighth place, participants believe SWDRI is another competitive area for the Kingdom. And thus, it contributes to the innovative capacity as well R&D concentration.

9. Saudi electricity company (SECO) Research Centre

SECO Research Centre carries out R&D in the electricity sector and produces periodical report.

SECO research centre is placed ninth in R&D as it contributes to the collective R&D in the Kingdom.

10. MOHE Centres of Excellence

As part of MOHE's new initiative, four centres of excellence are being established in a number of Saudi universities. Centre of Excellence in Nanotechnology (CENT) under KFUPM, Centre of Excellence in Renewable Energy under KFUPM, Centre of Excellence in Environment under KAAU and Centre of Excellence in Energy under KSU.

These centres of excellence are placed 10th by participants as they have a potential in contributing to the R&D in the future. These centres are in their establishment or early stages, KFUPM CENT was granted SR 12 [£2] million in November 2006, explains P30, this is being translated into research programmes, alliances with existing efforts in the Kingdom such as collaborating with Aramco, and initiating consultancy projects, also, it has formed an international advisory board.

7.2.4. Academic Institutions

MOHE manages all academic institutions in the Kingdom, the only institution that opts out of this system is KAUST, which was under development at the time of interviews and has operated in Fall 2009.

P21 believes that there is an administrative problem with the education system, this, she believes is quite alarming, she compares it to managing the blood flow in a body - when the management of a system is at fault, then the whole system dysfunctions.

Using international benchmarking in Saudi colleges and universities seems to be an individual effort rather than a government-led. For example, KFUPM has developed the RAM 1 and RAM 2 systems which is an international

standard for admission criteria. On the other hand, DAH has applied for accreditation and received it on personal initiatives of its dean; PMU has similar certification from US-accredited bodies. *[See next section]*

Moreover, P20 thinks that the quality of the education system in Saudi Arabia is deteriorating. He claims that the graduate of 99% grade of today is not better than that of an 80% grade twenty years ago. He blames the school education of the years before college, including: high schools and junior high schools. He believes Saudi curricula of education do not serve the market. He says: *“our biggest problem is in the general education is the regular [public] schooling”*.

P12 remarks that there are many new universities that are being established, especially within the past three years. He also adds that there are some expansion efforts for existing universities, in addition to the rise in the number of scholarships offered to Saudi students to study abroad.

P19 believes that apart from KFUPM, the remaining universities do not add real value and do not really contribute to economic development. He also argues that although there are many private universities and colleges that are springing up, he thinks that they operate more like business entities rather than home to R&D: *“They don’t have science, engineering or technology; In real universities there should be labs and research centres available”* he concludes.

According to the participants, the academic institutions by order of influence to economic development in Saudi Arabia are as follows:

1. King Fahd University for Petroleum and Minerals (KFUPM)

KFUPM is a leading university in the Kingdom and was established with the rise of the oil industry in East Saudi Arabia. It is a male-only university that offers degrees in science & engineering related to the oil industry, it also employs a programme of scholarships in leading petroleum engineering

schools in the world and its graduates constitute a considerable employment intake in neighbouring Aramco.

Placed first by participants in academic institutions contributing to NSI, many believe that KFUPM is an only academic institution that directly contributes to economic development in Saudi Arabia. For instance, P11 believes that direct contribution to economic development by collective academic institutions in the Kingdom is very thin, *“but if there is any contribution from universities it would surely be KFUPM”* he states. He further explains that most academic institutions submit to government bureaucracy by their affiliation to MOHE. He believes that universities cannot take active and leading roles in research when they are part of such bureaucracy. One reason he thinks KFUPM is bypassing bureaucracy is through its association with Saudi Aramco, he also expresses hope that KSU will do the same if it is to be embraced by SABIC.

P28 believes that KFUPM stands out because of its history which is longer than any other existing academic institution. P5 claims that the top 60% of Saudi Aramco employees are graduates of KFUPM. In fact, the current CEO of Saudi Aramco and the current Saudi oil minister, Mr. Ali Al-Naimi are both graduates of KFUPM.

KFUPM Research & Innovation Support Office was established in 1979, it is one of the main support offices under the Applied Research Programme at KFUPM.

P19 believes that because government exercise a central bureaucratic role in education, academic institutions in the Kingdom cannot function properly without the government because of funding dependency. Therefore, even the innovation centre is bound to such bureaucracy because ultimately the money comes from MOF, which finally finances the centre, this he adds *“consumes time”*.

i. Dhahran Techno Valley (DTV)

DTV is a KFUPM-initiative that acts like a science park for the university, it was established in 2006 and provides development, production, and marketing support services for innovation that is born at the university to transform into business– it provide a platform for industrial R&D in the Kingdom.

Some international companies that are present in DTV are the following, says P19: Schlumberger (oil and gas exploration) they have been there for 30 years and have developed more than 30 patents; Yokogawa (controlled system) has 5-6 technology sectors for development through partnership; Controlled system \$3-4 billion project between Honeywell Seimens and Tokogawa (90%) with Aramco (10%), giant oil fields; Tenures steel pipes, joint work with Aramco R&D points; Amianttit (the largest company in the world that produces composite pipes material) is 100% Saudi; Baker Hughes (engineering company); Aker (for oil and gas design and engineering). The Saudi government is the facilitator and funder (P19). Saudi Aramco spent \$400,000 on consultancy and \$1 million for DTV.

P2 criticizes the undertaking of DTV, and the lack of infrastructure, as he has witnessed it more closely. He explains that the park did not have the right physical infrastructure before it was actually established. He adds that water, electricity and telephone lines were extended from the airport to satisfy the needs of the science park including those international companies that were allocated spaces in that park.

2. King Saud University (KSU)

KSU is the Kingdom's first university established in 1957, it offers degrees under the schools of humanities, science, health and community.

It is placed second under academic institutions in the Kingdom that contribute to Saudi's NSI. Alumni of KSU are today ministers and member of consultative council as well as leaders in business and other areas.

3. King Abdullah University for Science and Technology (KAUST)

KAUST is a technical university established only recently in 2009 with an endowment of \$10 (£6.3) billion, and offers postgraduate degrees in 11 fields of study: life sciences, engineering, computer sciences and physical sciences; it has an extended areas of research in its research centres.

It is the only academic institution that is not running under MOHE, P11, a senior at the university, explains that one of the reasons for that is to avoid all the bureaucracy that comes with any government agency. P20 also believes that KAUST will play a significant role in economic development in the Kingdom. P11 argues that KAUST will produce graduates who are going to 'create' jobs via linking the talents inside the research institutes in KAUST with the business outside.

On the other hand, P14 although believes that KAUST will be amongst those academic institutions that contribute to economic development, yet it is still in its establishment phase and could as well be put in the same box as the economic cities "wild visions and everyone is expecting a lot" he says.

4. King Abdul-Aziz University (KAU)

Established in 1967, KAU is a public university in Jeddah that offers degrees under the following schools: economics and administration, economics, IT, arts and humanities, sciences, engineering, environmental designs, medicine, applied medical sciences, dentistry, pharmacy, earth sciences, marine sciences, meteorology and environmental sciences. Accredited by ABET Accrediting Board for Engineering and Technology, COP Council on Occupational Education, and GS geological society of London, UNDP united nations development programme, amongst others.

KAU is placed fourth under academic institution for its contribution to Saudi's economy and has produced graduates since its establishment that have taken leadership and policymaking roles and is expected to continue its contribution to Saudi's NSI.

5. Technical and vocational training corporations (TVTC)

Established in 1980 for the development of national human resources through non-academic training in technical units that cater more than 120,000 trainees across more than 100 locations in the Kingdom. TVTC has international cooperation in providing training such as Australia, Canada, France to name a few.

Participants have placed TVTC in the fifth place in its contribution to Saudi's NSI, as it upgrades the technical skills of citizens especially in rural areas. However, P20 thinks the TVTC is flawed and has yet to prove its role.

6. Dar Al Hekma College (DAH)

DAH is a private English-medium college for girls in the Kingdom established in 1999, it adopts an American model of education designed by TIEC⁴² its academic schools include: business, design and architecture, education and applied sciences, and law and international relations. It is the first institution in the region to achieve ACICS⁴³ accreditation. It accommodates 1500 students. DAH is the first of its kind in the Kingdom and has been placed sixth by participants and its one of the key institution in the education system in the Kingdom, it is not only a college but also a hub for societal linkages and brings about social change.

7. Jubail Industrial College (JIC)

JIC was established with RCJY in 1978 as a training centre and was upgraded to a college in 1982 JIC is a male-only college that now offers associate degrees in science and engineering, mechanical, chemical, electrical and instrumentation and control.

JIC is placed 7th in academic institutions; it has played a key role in transforming a rural society into an industrial modern one.

⁴² Texas International Educational Consortium (TIEC) is a consortium of 32 American universities in Texas.

⁴³ The Accrediting Council for Independent Colleges and Schools (ACICS) is a US-based institutional accrediting body that granted DAH full institutional accreditation in 2008 making it the first private institution of higher education in the region to achieve it.

8. King Faisal Foundation (Al Faisal)

Al Faisal is a private group of schools at various levels of education, it includes including: King Faisal Schools for primary secondary and tertiary schooling, King Faisal University, Prince Sultan College of Tourism and Management, Effat College, Al-Faisal University all for college level education.

Regarded as an influential contributor to economic development in Saudi Arabia, its education system and therefore the NSI. It is perhaps important to note here that late King Faisal has taken education to a new level by opening it for females in the 1960s, before which women were denied education. Therefore, he is regarded as not only a brilliant diplomatic leader who was regarded also so by the West but also as the liberal leader who freed the slaves and made education for women permissible. The figure of King Faisal is being maintained by the extraordinary foundation that support and develops education in Saudi Arabia. Effat is the mother of King Faisal. The group of schools contribute to social change and upgrading the educational level of the people.

9. Prince Mohammad bin Fahd University (PMU)

PMU was recently established in 2008 in the Eastern region, like DAH it adopts an American model also designed by TIEC. PMU is accredited by ABET⁴⁴ and SACS⁴⁵ and offers degrees under engineering, IT, business administration schools at college level and masters-level in business.

Ranked ninth by participants under academic institution, PMU is expected to participate in the Saudi NSI, especially with its focus on science and engineering disciplines to an international standard.

⁴⁴ The Accreditation Board for Engineering and Science (ABET) is a US-based accrediting body that accredits post-secondary education programs in applies science, computing, engineering and technology.

⁴⁵ The Southern Association of Colleges and Schools (SACS) is a US-based accrediting body recognized by the US department of education and the council of higher education accreditation.

7.3 Understanding the relationships and inter-linkages

Government-Industry-Academia Relationships

Most participants seem to believe that the relationship amongst government, industry and academia is 'very weak' with a considerable effort towards increasing and improving communication, adds P24. He further explains that the focus on R&D as a national priority in the past two years reflects a shift in attitude; while mineral resources of the country have been the sole focus of the economy and society, the objective of a knowledge-based economy is becoming increasingly important. Hence, there is a noticeable effort towards establishing the links between the three entities: government, industry and academia.

P22 describes the relationship as: *"a 'love and hate' relationship, they all need each other, yet, there are some problems in communication, trust and exploiting tools of communication"*. He adds: *"I believe we have the proper hardware, what we are missing is the software in order to activate it"*. As an example, P22 explains that the use of information systems and information technologies within these agents is malfunctioned and that has further complicated matters rather than facilitated it because the relationship is still set to its previous old way of communication, which makes all the investments in state-of-the-art technologies useless.

Likewise, P13 believes that the relationship is still weak and has a long way to go. He also believes that such a relationship is based on 'competition' rather than 'cooperation'. However, he adds that with the current vision of Saudi Arabia, we are all aware that the only way to achieve economic development is to cooperate together via the three entities [academia-industry-government inter-linkages]. Otherwise, he states, if the government continues to make their own decisions without consultation and inclusion of the industry and academia, this will risk hindering economic development. *"It is not a one man show"* he adds, and explains that collaboration needs to be strengthened at all levels and agents must realise that they are partners in the pursuit of economic development in the Kingdom. He further argues that the relationship

should not take a 'superior role', but rather a coordination role should be distributed.

Additionally, P21 on the other hand believes that efforts for communication are mostly done on a personal initiative and is not built on a well-established infrastructure. She believes that there are no channels that facilitate such communication on a regular basis. She adds that the communication is only done at the level of the ministers through the council of ministers but not at any level beneath that. However, in certain projects and subjects there are ad-hoc communications but such communications must be initiated or recommended by the minister. P21 gives an example of bureaucracy: in order to pass legislation for the environment the following approvals need to be granted through a hierarchy. The body responsible for the environment is the presidency of meteorology and environment (PME), which is under *municipal and rural affairs*, which is under the Ministry of municipal and rural affairs (MOMRA), which is under the authority on the Kingdom's regions which is under MOI whose minister sits in the council of ministers, this is an executive body that executes and recommends, it is then passed to the consultative council, which is a legislative body - an advisory board or consultative body. The king has to approve it then it is passed on to the relevant ministry to execute it. She stresses that the Kingdom runs very centralised managing: *"we sometimes face the problem of 'red tapes' – which requires too many processes and involve so many people to approve"*.

However, P21 is certain that change is coming to the Kingdom, albeit very slowly: *"change needs to be managed, it doesn't happen overnight"*. Today, the communication in the public is improving, media outlets has become more transparent and allowing for public voices to be heard. For example, consumer protection association is a new initiative that protects the consumer; this has been institutionalised in the country for the first time.

Moreover, P20 believes that the problem of lack of communication between the three entities is not new. He believes that because Saudi Arabia is a very young industrial / R&D society, the communication between academia,

government and industry is naturally very weak. He gives an example: the first educated Saudi batch started their education in the 1960s, thus, universities for example have suffered for a long time due to lack of good teachers, and therefore there is no single party to blame for the young society, it is an indication of how young the country is in existence and it becomes understandable why communication is still developing.

On the other hand, P18 argues that the lines of communication within the economy of Saudi Arabia is still not institutionalised and should not be relied upon. He also believes that the relationship between the three today is only ad-hoc. There is no sufficient flow of information for problem-solving between academia and industry. For example, the strong relationship between them is only limited to conferences, events, boards [of directors], and projects. However, he stresses that there are some recent initiatives that could lead to a more institutionalised relationship.

However, P15 believes that there is a relationship and interdependence between those three entities but it is unfortunate that the links are not strong, for example, academia has been largely focusing on academic activities such as teaching and research, which is again focused on teaching and promotion in the academic ladder. There was sort of a weak link between the academia and the industry due to the lack of applied research within academia.

Moreover, P10 believes that SAGIA plays a major role in improving the relationship between the three. For example, the advisory council of the 10x10 initiative that SAGIA has created brings together all the three to meet and discuss as members of the Saudi economy for the sole purpose to drive economic development. This, he adds, is perhaps a pioneering effort done in Saudi Arabia.

On the other hand, P3 describes the relationship between the three as “*fragmented*”. He believes that the relationship has to be more of a partnership and characterised by uniformity rather than “spotty efforts” as it is today. He believes that the government’s role is only to regulate but

sometimes it is over-regulating academic institutions. But KAUST, he explains, will be free from such limitations, which makes him very optimistic about the project, also because it is the initiative of the King, he will make sure its quality does not stray from excellence.

Also, P17 adds an example of a sustainable and strong link that currently connects the three institutions, for example, MOF which allocates the budget to DTV which is part of KFUPM that falls under MOHE.

Similarly, P1 believes that the nature of the relationship between the three is getting strengthened through many initiatives being established, such as: The Industrial Cluster, The National Innovation Initiative. Before, he argues, the relationship was worse.

P26 explains that he believes the reason why the relationship is not strong is due to the lack of a unifying vision that drives all agents to work towards it. He gives an example of Malaysia's '2020 Vision' and thinks that Saudi Arabia should develop a similar vision. However, he also believes that Saudi Arabia has had such a vision during the establishment of SABIC in 1976. The government decided to embrace the industry of petrochemicals and once this was announced, major projects were initiated such as the establishment of the two industrial cities, Al-Jubail and Yanbu', as well as inviting FDI and joint ventures, and the creation of The Development Fund. All these achievements, he argues, are as a result of such a unifying vision that must continue to happen today.

P25 states that there is a direct relationship between the three, the government provides incentives to companies and scholarships to students. He gives an example of KAUST as an example of the many social goods that the government continues to offer, he argues.

P16 thinks that the communication between these three is improving now but should be much better than it is. He also adds that such communication is limited to committees of a particular study or project, representatives meet on a regular basis for that objective only. In addition, he explains that the process

does not involve anything electronic or dynamic, but rather still rigid. However, he reassures that there is a lot of interest to improve, even though communication is regarded as secondary and not part of the core activity of the work.

P16 continues to explain the reason for such lack of communication by attributing part of it to 'culture'. He explains: *"Although Saudis in general tend to like to socialise and meet with family and friends on a regular basis at Al-Majlis [literally: a sitting place], however, when it comes to professional relationships they tend to get busy with different tasks of their work and leave"*.

Similarly, P23 seems to agree with P16, that the Saudi society seems to find communication problematic. He argues that it is often kept to a minimal and is not well-established, there is no platform to exchange information. P23 gives an example by saying: *"I am active in academia, many universities contact me and they don't know what is happening in other universities, it is like each is in an island, sometimes even within the same university"*. However, he stresses that there are always efforts undergoing to improve communication.

Furthermore, P16 adds another reason for weak communication which he believes is the planning process that everyone wants to be responsible for, he believes that there is a collaboration problem: *"This is my territory, I don't want people to come across this line"* he says, 'teamwork spirit' must be further developed, sometimes, even within a single organisation.

P16 believes that KACST tries to bridge the gap between the three and in fact has a number of programmes that have been initiated for this purpose. For example, BADER incubation programme, which is a programme to incubate start-up companies and fund them for the first years until they grow. In addition, KACST is adopting national technology companies that will bridge the gap between research and industry, he adds, KACST plans to be in charge of such companies with the objective of commercialising the outcome technologies and innovations across the Kingdom. He says: *"There is a*

department for SMEs as part of MOCI, also the Saudi credit bank is funding a lot of SMEs – the engine for growth in most economies and certainly one of the areas that need to be expanded in the Kingdom”.

Moreover, KACST is currently active in funding research in universities, incubators and programmes to promote technology transfer, explains P16. KASCT also invites different agents to participate in the progress of STNP. For example, P16 continues to explain that it brought together five different ministries to work closely on the policy: MEP, MOPMR, MCI, MOHE, and MOF amongst the total 42 organisations involved in the formulation of the KACST-led STNP. He stresses that the relationship between KACST and other ministries is strong, especially with the advent of STNP, such relationships are becoming well-established with regular meetings, he argues.

In addition, P15 believes that the communication between these three and within them creates the biggest challenge. He explains that because the process of getting a piece of information is so bureaucratic, one would rather find alternative sources abroad at international agencies. He explains that there is no understanding of the value of flow of information: *“bureaucracy is the main hindrance to economic development in the Kingdom”.*

P23 gives examples of what he believes are effective knowledge flow between the three entities: events, forums and exhibitions – *“there are no other ways to learn about new things”*, he says. Although there are two-dimensional relationships as will be explained below, a formal three-dimensional relationship that involves the government, industry and academia rarely materialises.

7.2.1 Government-Industry Relationships

The relationship between the government and the industry varies, P24 believes that such a relationship is embodied between MOPMR and Aramco, which he assesses as very strong and effective within the prescribed responsibilities. After all, MOPMR also sits on the board of trustees of Saudi Aramco. P3 agrees that the relationship amongst the oil and gas sector is

very strong, he says *“KFUPM and Aramco share an outstanding relationship!”* He also adds that the primary providers of engineers, 60-70% of petroleum engineers in Aramco are KFUPM graduates. Moreover, P6 also agrees, he adds that 78% of research grants received in KFUPM are from Aramco.

“Aramco is the most important enterprise in the Kingdom” P28 says, he explains that the government keeps a close eye on how Aramco runs its business, how it progresses and how it conducts its business locally and internationally, but he describes the relationship between Aramco and MOPMR as close and distant at the same time: *“Distanced in the sense that the government does not influence Saudi Aramco’s decision-making nor is it involved in the day-to-day operations”*. Saudi Aramco tries to establish and maintain itself as an independent enterprise, he claims. P13 seems to agree with that the government’s supervision role to Aramco is very minimal, *“they only set the guidelines and Aramco does the rest”*. Aramco, he explains, has long been regarded internationally as a ‘standard’ example of how an oil company should run, especially the level of independence that the company enjoys. There are some instances, he notes, where Saudi Aramco must submit to some pressures with regards to in-Kingdom pricing of energy distribution and allocation of scarce commodities. He stresses that the amount of influence and involvement of the government is a ‘delicate balance’ that needs to be managed extremely carefully.

Similarly, P19 also claims that the relationship in the oil sector is unique. This is evident, he argues, in that the MOPMR is a full member at Aramco’s board of directors; the CEO of Aramco is also part of DTV – they all meet on a regular basis and have sound relationships.

In addition, P12 explains that the government supports the industry in many ways. For example, Modon was supported by the government and has provided up to 50% of the capital required to start this industrial project, the government also facilitates the imports and exports of materials, and provide cheap raw-materials for oil-related downstream industrial projects.

Furthermore, P17 believes that the relationship between KFUPM and the industry is strong and has been established over 25 years ago, he explains the industry by dividing them into three categories: (i) Giant industry group such as Aramco, SABIC, SWCC, with this group the relationship varies depending on the management perspective. Aramco scores 9.5 out of 10; SABIC 6 out of 10; and others 0 with one direction, students at KFUPM are also workers at the industry, so it is almost non-existing; (ii) Middle industry: this is the mainstream industry sector, there is no relationship between this group and academia, there is a liaison office and consultancy service that brings the two together but this relation could be ranked weak to poor; (iii) SMEs: Only in 2008 the relationship was established, for example, KFUPM can be seen as a one-way relationship by providing education and training.

P17 summarises that the communication between and within agents varies depending on the management of these entities. Within the government, the flow of information is formal and very slow. In the industry, there are a few attempts from Aramco and SABIC such as technical meetings and discussions, common seminars and conferences – it happens a few times, and within other sectors the relationship is very weak.

7.2.2 Industry-Academia Relationships

KFUPM, which was created by Aramco, gives a unique picture to the role of academia in the industry, explains P19, therefore, since its inception, Aramco has been the greatest supporter of KFUPM, members from both institutions share an industrial advisory committee, also, KFUPM is the first provider of engineer graduates to Aramco. Similarly, P25 and P27 also provided examples of a number of on-going projects and research between Aramco and KFUPM.

Furthermore, P7 also believes that the industry-academia relationship embodied in Saudi Aramco-KFUM is unique for the reason that the former has established the latter. Therefore, the benchmark of such relationship is invalid to the remaining institution in the Kingdom. He says “*Saudi Aramco is like the*

God-father for KFUPM'. P29 Also agrees that KFUPM and Aramco make the strongest link across sectors.

P18 gives an example of KFUPM and how they started an initiative to bring together their various heads of departments in the boardroom. The board is inclusive of many individuals, including: 4 academics, 2-3 from every department and the rest from the industry. Their role involves reviewing curriculum, product training, and coop programs. This is an example, he believes, of an institutional mechanism for feedback between academia and industry.

In addition, P18 further argues that KFUPM handles industrial research for a number of companies, including: Schulmberger, Saudi Aramco, and SABIC. The CEOs of these companies meet with the president of KFUPM on a regular basis, they provide funding for these research projects.

Moreover, P14 believes that there is no interface between the three entities [government, industry and academia]; he further believes that there is no true win-win partnership in the area of R&D. For example, he states that MOF does not spend a lot on R&D, in fact, they don't use it; they buy technologies from the West and the East and use it, however, today, he adds, there are some initiatives towards improving this. For example, SABIC has recently signed a partnership to establish an R&D Centre in plastic at KSU, which remains in the thinking and talking stage, not yet in the establishment phase.

Also, P5 asserts that such a relationship [academia-industry] is very present, and this is evident in the creation of science parks in KFUPM, DTV with 13 or 14 international and local companies signing to have their presence in the science park.

7.2.3 Government-Academia Relationships

The government-academia relationship could be defined via two routes: the superior relationship between MOHE and all universities, and the funding/incentives-based relationships from the government to universities.

An example of the latter is the establishment of KAUST, which is the only academic institution that is not under MOHE. This, argues P11, is a way to prevent the vicious bureaucracy that naturally comes with any government ministry in the Kingdom.

In recent years, P24 notes, there has been a clear shift in promoting education, R&D and knowledge; One-third of the national budget has been dedicated for education. The establishment of KAUST is a clear example of a new government direction toward education reform.

P25 gives an example of the relationship between government and academia, which is defined by a rather limited approach: a direct one-way relationship where government funds universities, provides incentives and scholarships as well as access to training. Also, P29 adds that such a relationship is very weak and is not structured and is also based on occasional projects or consultation as needed.

An example of government funding to academia is the Chairs of Knowledge which was launched in 2007, hundreds of scholarships are given to young Saudis to pursue their education abroad (mainly in the USA). The outcome of this programme is yet to be seen, participants expect to see the fruits in the coming years with the first graduates start returning back to the Kingdom.

P18 tells a story during his time at the navy office where he worked as a head of the province in the Western region, he gives an example of an incident that occurred in 1991 that shows the cooperation between academia and government. There was an oil spill in the Arabian Gulf after the gulf war, the government wanted to limit it and control it but they couldn't tell how much it has expanded so the government requested that KFUPM conduct research on the subject, KFUPM came back with a mathematical formula done by the research institute in KFUPM to predict the exact motion of the oil spill so they could get rid of it. There was also a similar equation developed for another incident. There was an unidentified floating boat in the gulf that was loaded

with weapons, a similar mathematical equation was developed to reverse the motion of the boat to see at which country did it start.

P19 believes that the government must lead the role to facilitate an interaction between the industry and the government, although they have established science parks and technology zones, yet the focus should be on building a strong alliance between industry and academia so that the latter serves the needs of the industry and therefore drives economic development. He compares this to the UK experience in the 1980s where the government only provided financial support to those institutes that produced money, that way universities guided their research and resources towards the needs of the markets, industrial factories also conducted research – he explains, that’s how strong the relationship should be in the Kingdom between industry and academia. The role of research and academia in the rise of industrial revolution in Britain is vital, he believes, only if Saudi Arabia has this strength in alliance between industry and academia will it generate money from academia to industry for economic development.

Moreover, P12 notes that although there are some minor established relations between the government and academia, there is a need to intensify it. He gives an example of tax-break that is given by some governments to industries when they cooperate with academia –a similar mechanism should be developed in Saudi Arabia to encourage such an alliance, he suggests.

P11 adds that there is ‘very little’ cooperation between the two and that it is in fact limited to academic institutions producing graduates and the government baring the burden of providing jobs in the market. *“We must reform this in order to reach a point where graduates produce jobs and industries rather than be a liability to the economy”* he says.

In addition, P11 also agrees that any relationship that links academia with the government is often based on a *personal initiative* with no proper procedural structure. Similarly, P4 agrees that there is no incentive or driver for communication between entities, but at a personal level, Mawhiba tries to

establish communication with other ministries and universities; for example, Mawhiba has recently signed a memorandum of understanding (MOU) with KACST to identify their role as an innovation-driving project. It also has an MOU with MOHE to help with the identifying giftedness and creativity amongst students, this platform, he explains, will be utilised in the selection process to nominate students for scholarships, even in future-KAUST.

On the other hand, P7 believes that because MOHE supervises all universities across the Kingdom, the relationship between government and academia is strong. However, he explains that academia has no other links with the government except for ad-hoc projects and committees formed to meet [regularly] for that purpose.

However, P2 gives an example of the government-academia funding relationship through research grants. He believes that these often lead to *“useless outcomes and a complete waste of resources”* as he puts it. He explains that universities sometimes agree to take on any research grant just to get the funds, regardless of its relevance or significance. He narrates an example: *“In KFUPM, a research grant was given to research ‘cloning of human beings from protein’, the doctoral researcher went on five or six trips to Japan and finally outsourced the entire project there, paid the Japanese for their work and never made use of the outcome of the research.”* P2 believes that this is only one example of many similar cases for wasted resources. Therefore, he stresses that each university within the Kingdom should focus on a specific specialty area that is strategic and directly serves the economy of Saudi Arabia.

7.2.4 Ministries communications

Participants inform that the communications between ministries varies from one to another and the nature of communication dictates the strength of such communication. For example, the relationship between government and industry represented in MOPMR and Aramco could be perceived as ideal relative to that of other ministries. *“The relationship is very strong and*

effective within the prescribed responsibilities towards one another,” says P24.

However, P13 believes that *bureaucracy* is the main hindrance to the communication between ministries, he explains that the bureaucracy problem is rooted in the mentality of the government workers who “...*worry that if they are transparent or open to the public then this might jeopardize their positions and cost them their jobs*” he states. However, he mentions that there is some restructuring taking place to eliminate unnecessary agencies and procedures, though it will take a long time to materialise.

Likewise, P11 sums the nature of communication between ministries in one word: “bureaucracy!” he believes that in order for change to happen, the ministry must change its way of conducting business and not continue on the same old way as it has been in the past 30 years. He gives an example of the Singaporean government and how their new structure of their ministry allows two ministries to operate at the same time, one –he explains- maintains the bureaucratic role, while the other one is a CEO-like leader who runs a business-like ministry. The same applies, he adds, to neighbouring United Arab Emirates (UAE) whose government system overcomes bureaucracy by their prime minister running the country like a company. On his first day on duty, he explains, the Prime Minister asked all ministers to take off their *bisht*⁴⁶ and get down with business attires to produce results. He adds that this country [UAE] is neighbouring Saudi Arabia and shares the same culture; yet, they have been able to overcome some of the bureaucracy problem. He states that the king of Saudi Arabia has granted complete empowerment to every minister and yet that have not produced results, “*bureaucracy is killing the ministries,*” he adds.

⁴⁶ A traditional male cloak in the Arabian Gulf region, it is typically worn on top of a *thobe* [a dress-like male clothing] in special occasions rather than day-to-day. Hence, NAN’s reference is similar to saying “it is time to roll the sleeves up”.

Moreover, P3 believes the communication between various ministries is “*very outdated, [physical paper] letters still have to go through from ministers to vice-ministers by hand, there is no email-based communication*”. He describes the way of doing business within ministries as “*paralysis*” – this, he adds must be reformed. However, he believes that it is not right to take this fault as an excuse for doing nothing. Despite all impediments, he says, Aramco is achieving and conducting a lot of R&D and is currently also managing the KAUST project. He adds: “*Today, we are running uphill and with the government bureaucracy, I just have to run harder*”.

Furthermore, P2 also believes that the relationship between ministries is “*completely dislocated, they still use paper!*” and P17 also describes it as “*very ineffective*”, P16 agrees that it is still not as efficient as it should be, he stresses that communication is not being institutionalised as part of the core work of organisations. He gives an example of France where a single agency is required to report back to three or four different ministries where a joint-decision is considered. On the other hand, in Saudi Arabia an agency only reports to a single ministry, if it reports at all. He adds that “*it is not part of our governmental structure to embrace linkages, joint-approach is only observed in research-industry projects*”.

On the contrary, P10 believes that the communication between ministries is “*well-established*”. In fact, she adds that they work as partners in an interactive communication and that they share inter-related work. This is especially true, she adds, where there is a cross-ministerial project. She explains: “*there is often a misconception about the ministerial work that is done which is quiet opposite to reality*” – she affirms that it is based on cooperative work towards developing Saudi Arabia. “*Not a one-man-show as so many think*” she says.

Similarly, P8 seems to agree with P10 in that the communication between ministries is “*very strong and in fact it is in a good shape*”. However, he criticizes some impediments such as not using the Internet and the old and rigid way of conducting business.

P15 argues that because all ministers are part of SEC, it is assumed that there is a rather good communication taking place. However, this communication must improve especially when redundant work is being carried out by two different ministries without them knowing, *“the loser in this case is our national economy”* he states.

7.2.5 International Networks

P10 explains that the private sector has a very sound relationship with international companies. In fact, she believes that the Kingdom’s development projects are based on such collaboration that it cannot survive without. She gives a number of examples: (i) MOCI has recently hosted a visit by the Singaporean government to learn and exchange knowledge; (ii) the healthcare sector in the Kingdom continuously seek similar collaborations; (iii) SAGIA has participated in a collaboration with MOJ in Singapore *“we have learnt from their experience 2-3 months ago which has contributed in the process of reforming Saudi courts”*; (iv) a partnership between KAU and ZP (a German company) to develop knowledge parks; (v) a partnership between KSU and ZP, the same group, these, she explains, are only some of many strategic partnerships that drives the Kingdom.

7.3 Knowledge and Learning

P13 believes that the education system should be placed at the heart of the national economy, and efforts must start from the early years of education in the society, he claims that studies show that 60% of capabilities are developed at this early stage of kindergarten. Therefore, this forms the foundation of learning in the society and should not be overlooked, especially that numbers today show extremely low admissions in kindergarten in the Kingdom. Furthermore, efforts geared towards establishing a Knowledge-Based Economy (KBE) must first focus on increasing the Kingdom’s competitiveness in a knowledge-edge. He says, *“Oil does not mean anything to Saudi Arabia if we do not translate that into how to be innovative and how to compete”*, for example, he adds, the Kingdom should learn from Japan’s

experience in moving from a knowledge-driven rather than resource-driven economy.

On the one hand, P25 states that Saudi Arabia's quest for knowledge and learning towards becoming a knowledge economy is still emerging with a need for improving technology and knowledge transfer.

On the other hand, there are some small-scale internal programmes that could contribute in the general knowledge and learning of the organization, says P14. For example, Aramco has a programme running since 2002 to manage knowledge and exploit ideas, called The Innovation Programme. Likewise, P24 explains that this program promotes innovation through the use of a management system accessed by all employees, the interface allows to transmit ideas to the management committee, in turn, they process and evaluate these ideas as they receive it. P24 is a member in the environmental committee and says it receives a total of about 40,000-50,000 ideas per year and have utilised some of them that have generated \$500 [£312] million in process improvement and cost reduction. In addition, the same programme enabled the registration of 40-50 patents of innovations based on ideas submitted through the system. In fact, P17 asserts that the Innovation Programme at Aramco has saved them a total of \$1.5 [£0.9] billion in operation. On the same lines, P14 adds, Saudi Telecommunication Company (STC) has recently developed a similar programme called The Knowledge Program to enable STC employees to share their knowledge within the company.

Moreover, P8 believes that the government is initiating projects to position Saudi Arabia as a KBE. For example, the E-Government programme, he believes, which is planned to operate in 2010, promises many reform to the out-dated system that is currently in place: *"The current way of doing business remains like the old days, such as bureaucracy, no use of internet, and processes that takes too much time"*.

In addition, P27 believes that the quest towards a KBE in the Kingdom is “just starting now”. He explains that Saudi Arabia is just at the beginning of its learning curve and there still is a long way to go. He adds that KFUPM is participating in this process via its collaboration with international institutions and through its work with the industry. The establishment of DTV as part of KFUPM is an example of such an effort. In addition, there is a new Centre for Innovation that has also been established in KFUPM. These institutions, he adds, have started only 2-3 years ago and have formulated policies that are required to encourage young engineers and researchers to come up with new technologies.

However, P28 argues: *“there is a lot being ‘said’ within the Kingdom about pursuing KBE, however, the reality is that education is lagging way behind and that is especially true for women’s education”*. He explains that the spending by the government on education per pupil is very minimal as compared to that spent by developed and emerging economies. He stresses that there are so many new projects including the establishment of new education institutions, however, he believes such development needs to accelerate to enable a transition towards KBE.

Likewise, P20 believes that Saudi’s knowledge and learning process is very weak, this he argues goes back to the general education system. For example, in 2000, P20 explains that he had a student joint-supervision at KSU in mechanical engineering who was *“incapable of distinguishing between the size of a litre and a mitre cube”*. He adds that this is just one example of many that prove that students enter college poorly prepared. He also attributes that to the general education system in the Kingdom, which is mostly based on ‘memorizing’ rather than understanding, articulating and reasoning.

Nonetheless, P20 argues that Saudi Arabia is a young society in every aspect: *“If general education has failed us,”* he argues, *“how can the process of industrialisation occur and how can we contribute to economic diversity when there is no real R&D in the country”*. He adds that according to UNIDO’s categorisation in terms of technological intensity of products, Saudi Arabia

has the lowest rank category, which is basic raw-material (oil), it is resource-based country and lacks medium to high technology sectors.

P20 is part of the National Industrial Strategy team, which – he explains – has recognised the pressing need for the Kingdom to improve its ability to produce more technically-developed products and lead a multi-faceted economy. Additionally, P20 explains that the workforce in Saudi Arabia is problematic, the challenge is not finding high-skilled Saudi labour. He argues that there has been a heavy reliant on expatriate workers and especially for low-skill jobs because companies cannot afford to pay for Saudis who will not accept to get paid so low.

Similarly, P18 seems to agree that human capital in Saudi Arabia comes with challenges. He adds that there is no clear structure for learning because the country lacks connectivity between all existing ‘islands’ of very primitive efforts. He explains that it may be because Saudi Arabia is a rich country and has taken advantage of its oil resources, *“this is the curse of the [oil] wealth”* he says. He thinks that for many projects, for example KAUST, they are overwhelmed with a huge budget.

Asserting the point, P17 also believes that the Saudi economy has been based on commodities since its inception, and therefore, placing knowledge generation as a commodity will be the biggest challenge. He adds that the statistics of patents and IP created in Saudi Arabia is close to zero. Hence, he believes that the Kingdom has not yet reached maturity in understanding the process of funding for R&D and innovation. He argues that there is neither an infrastructure nor the experience to support it. However, the initiatives that have just started now may result in some development, for example, KBE and national innovation ecosystem (NIE) project being planned at KACST.

On the other hand, P15 believes that there are serious efforts by the government to pursue a KBE. For example, SAGIA and Al-Aghar are involved in developing the NIE through a partnership with the Malaysian government for the purpose of learning from their success story of economic development.

Likewise, P14 agrees that there are efforts being made towards KBE especially by Al-Aghar group, Mawhiba and MEP, he adds. He also mentions some projects that are being undertaken such as the plan by MEP to transform the Kingdom to a KBE by 2020, the national policy for science and technology by KACST and the work of Mawhiba.

Also, P7 explains that the Kingdom has a number of initiatives that have been on-going that are trying to take Saudi Arabia on a path towards a KBE. Al-Aghar Group has done an outstanding job, he argues however that they have limited resources and that initiatives are still made by a few people.

Moreover, P12 argues that the Kingdom has allocated a huge budget on education which is evident in the creation of new universities. However, he believes that the Kingdom still lacks the right incentives for information dissemination that is necessary for creating new knowledge. P12 gives examples of similar initiatives to promote innovation: (i) One recent initiative is BADER, which provides incentives for technological innovation in the Kingdom; (ii) Yasser, which aims to create an E-Government system.

Still, P11 believes that the knowledge and learning process in the Kingdom is very basic. He argues that the term KBE is not really understood within the circles of government, academia and industry today across the Kingdom. He adds that the Kingdom needs research institutes that should form the medium between “the money outside and the brains inside”.

In addition, P5 believes that although the Kingdom is not equipped for knowledge-generation yet they are moving in the right direction. This is evident, he argues, in the high percentage of Internet usage in comparison to the average in the Middle East, and also, the government has announced that by 2010 through the Yasser E-Government Program there will be 150 services available online. This is an indication, he argues, that the government is driving its society to use Internet and online facilities as a step forward towards KBE.

Similarly, P3 believes Al-Aghar group represents aspirations, plans and projects to transcend the Saudi economy into a KBE. P3 further adds that *“we must identify the building blocks of a KBE, the first one being education”*. He argues that this has been identified and it is evident in King Abdullah’s Initiative for Education (Afaaq). He concludes: *“I think that everybody that has been looking into the Kingdom knows that our king is both a reformer and passionate about education and knowledge, which is evident in the generous re-allocation of resources”* (P3).

P1 adds that the learning process is still at its early stage with very primitive innovation initiatives such as the science and technology policy, which includes element to support the existence of a KBE. Similarly, P23 adds: *“We certainly don’t have all the tools”* on the Kingdom’s pursuit to KBE.

7.3.1 Market Competition:

P13 believes that the leading role is set by the private sector, so efforts should be focused to improve the latter in order to support economic development. He also argues that not until the private sector realises the role that they are set to do, market competition will be limited. The role of the private sector he believes involves improving the quality of domestic products (supply) so that it prevails over imports. He also notes that product ‘innovation’ sets the demand in the market. P13 adds that for KSA being a WTO member requires a need for a radical transformation of the private sector. He believes the latter is more mature today than it was before the Kingdom’s accession to WTO.

Similarly, P15 explains, the industry is geared towards maximizing profit and improving the overall performance within activities. Competition is two-fold, P15 explains: (i) in the local market, SMEs find competition from imported cheap products from Chinese and Asian producers. Therefore, the industry’s biggest challenge is to make sure that their prices are competitive; (ii) in the global market, cost is another important element for SMEs, competition in exports at a global level is a challenge, for a bigger market share SMEs must employ continuous product improvements and research activities that will

make [Saudi] products superior if not at least matching the prevailing global standards. This is achieved, he explains, when there is prevailing research activities geared towards improving product performance.

On another note, P26 believes that a technology demand-pull is present in the Ministry of Defence where latest technologies is constantly demanded and acquired from abroad, the industry and science programmes. He believes such a technology pull in Saudi Arabia is very weak and is based on acquiring technologies from abroad. However, P16 points out that Saudi Arabia's aim is to become a KBE and for this reason it should opt out from the 'local market' sphere into the 'global market' sphere. This means that it should not look for technology-pull from within Saudi Arabia only but also from abroad.

On the other hand, P28 explains that there are only two major demand-pulls for local technology development in the Kingdom: (1) Maximizing oil and gas recovery, exploration and production and (2) Maximizing production efficiency of petrochemicals. Both demands, he argues, are namely from Aramco and SABIC. Other than these two entities, he believes there is no demand-pull for in-house technological generation and development. He adds that the easy way out for companies is to license and buy technologies from *abroad* and use it.

Similarly, P16 believes that from the supply-side of technology, most of the industries in Saudi Arabia (if not all) – he argues – are *licensed technology* and do not have IP transfer requirements. They do not require companies to transfer and/or develop technologies, therefore, technology providers only focus on 'selling' the technology rather than 'develop' it. This problem, P16 elaborates, is due to the local mentality that thinks high-quality products are not attainable locally. He argues that there must develop a different way of thinking, perhaps then, local companies would transfer technologies and get the licenses to develop it jointly.

In addition, P20 argues that the commercial system in the Kingdom is based on demanding "*fast answers to pressing questions*". For example, he explains

that SABIC works with foreign counterpart via joint-ventures to get answers faster and easily, rather than acquiring knowledge internally which will take them a longer time. He concludes that there is a high demand for answers to technical problems and the only supply-side available is from foreign counterparts.

However, P7 believes that “*Saudi Arabia is a green virgin market*” in that the demand is always there. For example, he explains that the ICT sector has flourished in the past years with skyrocketing Internet use demand. Al-Gaseem region currently has 10,000 Internet subscribers and the waiting list is 20,000 because the demand outnumbers the infrastructure and the current capacity. In fact, he adds that the estimates are that in five years time the number of subscribers will reach 150,000 with over 700,000 in the waiting list. He explains that Saudi Arabia has a growing population and the market demand is only growing, this he argues will positively impact the economy. Similarly, P8 discusses the social aspect of technology, “*technology literacy is becoming increasingly widespread especially amongst the younger population*” which he argues is a good indication of an increasingly knowledgeable community that will eventually impact market dynamics compared to 30-40 years ago.

P7 identifies major sectors in the Kingdom that would provide a competitive-edge: (1) information and communications technology (ICT), Communications and Information Technology Commission (CITC) has conducted a study about the current state of the sector; (2) Water technology; (3) Renewable Energy – solar and wind. “*We have both money and energy so we could use the chance to continue to remain a leader in the energy global arena*” he states; and (4) Healthcare – which he explains is an imperative sector that must be prioritised in Saudi Arabia, “*50% of the population above 45 years of age are diabetic*” he says and explains that research has to be done to “*isolate the gene*” and exploit opportunities available to advance the healthcare sector

and medicine R&D, for example, the *Hajj*⁴⁷ season presents an opportunity for the Kingdom to isolate the flue virus “*by asking to swipe the tongue of every pilgrim*”.

7.3.2 Rate of Technological Change and Innovation

P5 argues that ‘technology transfer’ is a biggest challenge in the market. For example, he explains that SABIC was established in the 1970s yet they still treat technical problems as a ‘black box’ and seek technical assistance from abroad. He believes that Saudi Arabia needs a ‘critical mass’ to solve its own problems. He gives an example of South Korea and how they have started their industrialisation process during the same time as Saudi Arabia did but they have accelerated and moved ahead because they have succeeded in upgrading their human capital to activate ‘technology transfer’. The statistics show that for every 10 graduates in Saudi Arabia there are only 2.8 engineers, whereas in Korea it is 7 out of 10, that is not enough for advancing the Kingdom.

Likewise, P26 explains that the problem with Saudi Arabia in knowledge-flow and technology-transfer is that the communication channel between ‘the sender’ (being the technology holder) and ‘the receiver’ (being the Kingdom) does not exist. People in Saudi Arabia, he believes, tend to want immediate solutions to their technical problems and therefore, all technologies that they are adopting are bought ready from abroad. The bigger problem, he argues, is that there is no incentive by the government to develop it in-house and there is no disincentive (e.g. tax) to bring it from abroad. Therefore, almost all companies lack the long-term vision of developing technologies.

However, P13 argues that the rate of technological change and innovation is set by FDI in the Kingdom. He argues that this is good at the beginning because not only does it generate money but also brings expertise and

⁴⁷ *Hajj* or pilgrimage is the season when the kingdom witnesses an influx of thousands of Muslim visitors to the holy land of Makkah Al-Mukarrama.

technology that is up-to-date. He adds that Aramco is at the forefront of technology transfer and diffusion and may be regarded as the only sector in the Kingdom that is not only a 'recipients' of technology but rather a partner in developing and implementing it. He adds, SABIC falls in a similar role in terms of efforts for technology transfer and diffusion. Confirming that, P13 states that the two major sectors that show mature utilisation of technology are the oil industry and the petrochemical industry, namely, the key players Aramco and SABIC. P13 further adds that the 'service' sector in the Kingdom is developing very fast. He believes the service sector, which includes tourism, banking and others are currently embracing global competition and has the potential to follow the paths of the oil and petrochemical sectors.

On the contrary, P25 believes that in the main industrial pillars he argues, namely SABIC, Aramco and SEC, technological change is slow if not stagnant. Water desalination and electricity generation, he adds, both use the same old technology that has been used in the past. In fact, electricity generation still uses crude oil as a source of energy, which is very environmentally damaging, expensive and inefficient. P25 believes though that the main sectors in Saudi Arabia with a relatively high pace of technological change are the banking sector, healthcare sector and ICT. However, he adds that innovation is usually carried out in medium-tech to high-tech sectors, *"the main export is crude oil, there is no medium or high-tech sectors in the Kingdom"* P25 says.

Similarly, P23 also stresses this point that the water sector, his area of speciality, is lagging behind in technology: *"the machinery used for water desalination is very inefficient and was in fact dumped from European markets in 1970s when they started implementing fiercer environmental regulations. They sold their old-technology machines to countries where environmental regulations are more flexible."*

While P25 believes that the rate of technological change is very slow and argues that, in general, the cultural identity in Saudi Arabia does not embrace change, *"the 'social inertia' prevents a lot of change ventures to prosper"* he

says, P16 believes that the rate of technological change in Saudi Arabia is in fact *adapting*, he believes that Saudi Arabia is in the process of building its infrastructure and research base and is moving in the right direction, it is just taking some time.

Whereas, P15 believes that the rate of technological change is dependent on how sophisticated the technology at hand is. He believes that SABIC has succeeded in technology transfer in a number of projects that he witnessed while working there. He explains that they initially import the technology and then develop it internally, and eventually, SABIC becomes the owner of the technology. For example, he narrates: *in the early 1990s SABIC and Institut français du pétrole (IFP) worked on licensing a particular petrochemical technology, it has become known under the name of 'IFP-SABIC Technology', which is a catalyst (process) for converting ethylene selectively to butane 1, this is an ingredient input for the manufacturing of plastic – both IFP and SABIC jointly license this technology to the world.*

“The role of technological innovation in economic development in Saudi Arabia exists but to a bare minimal”, argues P15. He explains that Aramco may be the only agent in the Saudi economy that have produced real innovations, he gives an example of one breakthrough innovation in the oil and gas sector that Aramco has achieved, which is the development of satellite technologies that enable them to explore and determine the size of the reserve within a specific location. There are other technological developments that he considered more of ‘improving’ or ‘upgrading’ technologies rather than innovation, he adds.

Similarly, P24 explains that technological change within the oil industry is unique. The oil sector in Saudi Arabia always applies cutting-edge technology. He believes that the utilisation and adaption of advanced technologies in the oil sector is ahead of all other sectors in the Kingdom. However, there is no major in-house technology development in Saudi Aramco but this has recently been taking attention. He argues that this is evident in the recent establishment of two research centres to focus on developing solutions in-

house. He adds that the petrochemical sector in Saudi Arabia is also strongly moving ahead, however other sectors he believes are lagging behind.

Moreover, P11 gives an example of the technology strategy used at Saudi Aramco, he explains that they have a clear direction and know which technologies to buy and which to invest in developing in-house. Likewise, he argues, at a country level the government should develop a similar strategy to identify which technologies to develop in-house and which to buy from abroad.

P5 believes that Saudi Arabia does not have any technological change or innovation. He compares the level of R&D done in the Kingdom to that of the USA. The latter he argues have 10,000 R&D labs that do not only serve the US but also serves the entire world, on the other hand, Saudi Arabia has nothing at all, "*we are blessed with oil so we have wealth and therefore we buy all the technologies!*" he concludes.

On the other hand, P10 believes that SABIC and Aramco are the Kingdom's main industrial pillars which define its technological change. However, she believes that the government supports and encourages technological learning via its new initiatives. It is in the king's vision to diversify the economy, in the last OPEC summit (2008), the king has allocated \$750 [£467] billion for establishing R&D in cleaner energy options.

In the area of innovation in the Kingdom, P3 says: "*we are obviously followers in this area*". P23 also agrees, he believes that the spirit of innovation is killed when the government refuses to take the risk to invest in new technologies. He explains that this has been the case in the electricity and water sector, which still operates on an old system that was designed by foreign consultants which the government accepted but has not went beyond this and refused to take the rest to invest in new technologies over the years.

Moreover, P26 also explains how long and inefficient the process of applying for a patent is in Saudi Arabia that it drives innovators away. He narrates an example of his friend who after a very long and complex process has filed for his invention to be registered, but due to very long waiting, he decided to

register it in a neighbouring country which does it at a much faster pace and more efficient way.

Similarly, P18 asserts that the most advanced sectors within the Kingdom are the oil sector and petrochemical sectors, *“I don’t think we have done any innovation that led to economic development”* P18 says. But even with SABIC, which he argues is the most industrialised, has acquired most of its technologies from abroad rather than in-house.

Furthermore, P18 explains that the healthcare sector and the education sector are both lagging behind in technological innovation. The education system uses average technology, he suggests, when considering four indicators: software solutions, remote learning, knowledge management, and e-learning. Also, the healthcare sector, P18 believes, uses limited technological advancements.

However, P1 believes that the role of technological innovation is evident in the ICT sector in the Kingdom. He argues that it is now in the blooming stage from the demand side in the market. For example, STC and other companies have developed technologies to satisfy the growing demands of the market.

Similarly, the telecommunication industry, P13 adds, is debated extensively. With privatisation, he believes, the pace of development and competition has increased. The deregulation process, in particular, has proved to be positive and effective in increasing competitiveness. He narrates an example: Ten or fifteen years ago, when a citizen asks for a telephone line it takes so long before the phone finally works. Today, you get it the next day – the same applies to mobile lines. This tremendous improvement, he claims, is due to the deregulation that raised the level of competition and therefore offered better services to the public. However, he states that ‘technology innovation’ is still very limited but *“since we are moving in the right direction, we will soon see technological innovation spreading”*.

7.3.3 Policies to Promote Innovation:

The 10x10 strategy aims to place the Saudi economy amongst the world's top ten economies in 'ease of doing business' index by the World Bank. As a translation to this objective, SAGIA has launched three major initiatives: (1) the national competitiveness centre (NCC) to monitor, assess and support competitiveness in the Kingdom; (2) the economic cities to diversify the economic base of the Kingdom by empowering the private sector and attracting FDI; and (3) raising sector opportunities by attracting FDI in the energy sector, transport sector and knowledge-based industries.

P18 believes that many of the established initiatives are results of policies that promote innovation. For example, The STNP that is being formulated by KACST; the process of inception of SABIC; the nationalisation of Aramco to Saudi Aramco; banning monopoly by the MCI and the Ministry of Communication, which has resulted in major changes in the ICT structure and the aviation companies.

"Promoting innovation is a very new direction for the Kingdom," P13 argues. He explains that there are some policies that have been recently formulated which promotes innovation. There are also a number of institutions that focus on the promotion of innovation such as Mawhiba and the future KAUST. P13 believes that with these growing efforts, the Kingdom is moving to the right direction towards the establishment of a knowledge-based economy. However, he stresses that it is important to change the 'gear' and move ahead faster because the business-as-usual scenario is not going to take the Kingdom anywhere. He also adds that the purpose of establishing SEC was to overcome bureaucracy and accelerate economic development, the same purpose is the establishment of SAGIA as well. However, P13 believes that it is easy to *fall in the trap of* bureaucracy if one is not careful.

P7 explains that SAGIA is formulating a strategy for the Kingdom via SRI, which in its capacity as a hired international consultant firm has interviewed 62 people from different sectors across the Kingdom to produce a report that

formulates objectives, requirements and a feasibility study for Saudi Arabia's transition towards a KBE.

Moreover, P7 also describes the outcome objectives of this \$10 [£6.2] billion research project led by SRI which was conducted in 2004: (1) Saudi Arabia is to be a leading country in the Middle East in KBE; (2) 10x10 programme which aims to place the Kingdom amongst the world's top ten countries in 'ease of doing business' by 2010; (3) Competence in different industries with an additional value of almost \$400 [£250] billion; (4) Create 500,000 direct jobs, 350,000 indirect jobs and newly highly paid jobs. He explains that many of the projects that are recently established were as a result of this study, such as KAUST, the innovation centres within universities, and the first conference on KBE by KACST and Al-Aghar Group in 2007.

In addition, P10 believes that such strategies have already been formulated in the Kingdom. She points to the following under knowledge generation, In the Kingdom's eighth development plan, the Council of Ministers in 2005 has approved the plan to diversify the economy away from oil-based and towards a KBE. Many projects have been translated from the strategy and are being established to achieve this objective, for example: (i) KAUST is a \$14 [£8.71] billion project, this is by far the largest endowment in the history of the Kingdom, focusing entirely on 'knowledge generation'. Six sectors have been identified, none of which is oil or oil-based sectors; (ii) Industrial Cluster which focuses on creating value proposition and enablers to support innovation; (iii) KACST was empowered in 2005 with SR 8 [£1.32] billion for the establishment of R&D centres across the Kingdom; (iv) NIE project established to create an innovation system for Saudi Arabia, this has been championed by KACST.

Yet, P19 believes that the Kingdom must first focus on particular technologies that are strategic for its economy and then develop technology roadmaps in order to achieve 'technological innovations'. "*Focus brings excellence and diversity empowers innovation*" he says. With the leadership of King Abdullah who is a firm believer in establishing good R&D in the country, the direction of

the Kingdom is moving towards a KBE and diversification its oil-base. P19 explains that this is evident in the new investments being made, such as the establishment of KAUST, KAPSARC and centres of excellence. However, he believes that the current efforts of organizations like KACST, SABIC and Aramco are yet general and lacks a technology roadmap to add value and stimulate innovation.

Although P17 believes that there are “*zero efforts geared towards innovation in the Kingdom*”, he describes considerable efforts at KFUPM that may result in stimulating innovation. For example, he explains that there is an incentive program for faculty for registering patents; the immediate reward is receiving 40% of the salary and also the chance to greet the king who will offer him a reward of SR 100,000 [£62,200]. However, he criticises this system for not including any support for commercialisation in the market, and therefore, innovations do not go beyond being mere inventions.

In addition, P17 adds that there are policies that support SMEs. For example, there are industrial development banks for financing easier loans for SMEs, and there is a human resource development fund dedicated for training Saudis.

Moreover, P26 suggests that Mawhiba is one institution that is dedicated to spur innovation within the academic arena, it encourages giftedness and creativity at a young age and supports it by providing incentives and rewards and by providing the right environment. However, he criticizes their selection process, which is done automatically by selecting students with top scores in schools. He also clarifies that Mawhiba is an institution for kids and not for genuine innovators.

Similarly, P4 also explains that Mawhiba is an organisation that promotes innovation through its programs and also through its alliances with MOHE, “*they have signed an MOU with universities to assess top students as prospective innovators*” he says, for example he explains that they have established links with future KAUST to nominate top 20 students from over

the Kingdom to receive scholarship. Mawhiba also has alliances with international organisations such as World Intellectual Property Organization (WIPO), ARICSO under Arab League and International Federation of Innovation Association.

However, as an example of an innovation-related initiative, P26 explains that there is a Saudi Society for Technology Development and Transfer that he is a member of, where they focus on conducting training to raise awareness about 'reverse engineering'. Especially when today, he believes, there is no technology development and innovation in the Kingdom and when everything is bought from abroad rather than developed internally.

Furthermore, P25 believes that the initiative of the Industrial Cities as a way to promote innovation in the long run, he adds "*It is the fabric needed to put in place before innovation could happen*". In addition, P8 also considers SAGIA's 10x10 initiative a policy to promote innovation.

For innovation policymaking, P24 believes that the Kingdom is heavily reliant on technical and knowledge-based consultation firms from abroad. He also explains that the education system does not encourage innovation. He describes universities as "*handicapped*" with their only resource being the faculty and lacking a real academic environment.

Also, P22 believes that innovation-based developments in the Kingdom is rather limited to the oil and gas industry and the petrochemical industry. He adds that Mawhiba is set to promote innovation via its projects and incentives, examples of its initiatives: research chairs, excellence centre, promote innovation amongst school students in the Kingdom.

Similarly, P18 gives examples of efforts done at KFUPM to promote innovation; he explains, there is an annual reward for registered patents and innovative solutions. The King personally attends the event and presents a medal to awarded participants King Abdulaziz Medal for First Class, Mawhiba is another organisation that also encourages innovation at a school level.

In addition, P7 states that the Consultative Council has approved the formulation of a strategy for intellectual property (IP) in the Kingdom, before which it was non-existing. He also believes that in the oil and gas and petrochemical industries, Saudi Arabia is *“ahead in the game”*, yet the remaining sectors are lagging behind.

Moreover, P2 believes that the first problem that Saudi Arabia must solve before it could pursue a KBE is the IP challenge. He argues that it is ‘the missing link’, there is no infrastructure or institution that protects the intellect and innovation of the people.

Furthermore, P5 believes that policies to promote innovation in the Kingdom could be seen in recent changes in direction of the two giants Aramco and SABIC, both of which are embracing innovation policies within their R&D centres. He further explains that ultimately, all government policies are there to drive economic development but the most important source of innovation is to have an organized interface between academia, industry and the government.

On the other hand, P23 believes that the reason behind the lack of innovation in the water and electricity sector is the lack of incentives for new technologies. He gives an example: *“In large sectors, the government provides very low energy prices, thus, you don’t get the most efficient designs for plants because as an investor or contractor you would want to build plants at the lowest cost possible”*. He explains that about 30% of the Kingdom’s energy is used locally to produce power and water.

In 2002, the king has approved the National Science and Technology Policy (NSTP), the main objective of the policy is to transform Saudi Arabia into a KBE by year 1444H (2023G) in about 20 years time. The policy was formulated as a joint effort between a number of organisations including: KACST, Mawhiba, Aramco and SAGIA. As part of the policy, there are five areas of focus to improve: infrastructure, human capital, governance, innovative capacity, networks and attitudes, and finance and capital.

P16 confirms that the approval for the National Science and Technology Policy (NSTP) by the Council of Ministers means that Saudi Arabia is put on a path towards KBE. He argues that the NIE study that is currently being conducted is to develop and improve on the 'innovation' aspects of the policy. He believes that the Kingdom should pursue 'balanced innovation' which ensures that all the elements within the NIE work together complementarily. For example, he argues that it is important to develop a good education system to have researchers. Therefore, regulations are an important part of the infrastructure and every component must work simultaneously.

P16 adds that since the approval was granted in 2003, there were a number of projects planned in the 5-year-plan. For example, there are more than 190 projects for 42 organisations and more than SR 8 billion allocated for the implementation of these projects. He explains that the funds allocated to KACST for the first year of the plan is \$400 million which is equivalent to what have been spent on KACST since its inception over 30 years ago.

P16 is confident that within 15 years, the plan is to have a KBE and society in Saudi Arabia can be achieved. He argues that the way to do that is to first identify the major players and the main elements of the 'ecosystem', then, focus on the main problems facing the Saudi economy of education, legal issues and problems with funding of institutions. Also, assess the infrastructure and its requirements of the country to move to the right direction. This, he concludes, summarises the implementation plan of the NSTP.

7.4 Understanding the institutional structure of the Saudi Energy Sector

7.4.1 Established links

P24 gives an example for Joint Industrial Projects (JIP) of oil companies that come together to discuss issues of common interests, they share funds,

discuss problems facing the oil sector in general and share the cost of research organisations. Aramco is a member in the JIP⁴⁸ amongst so many. He adds that there is also the Petroleum Environmental Research Forum (PERF), which meets regularly, supports collective research and establishes partnership with other research centres. Therefore, he continues that there is excellent communication channels and knowledge sharing in the energy sector in the Kingdom with the rest of the world.

P25 adds that the network that Saudi Aramco is connected to is very strong. It has sound relationships with universities, NOCs, IOCs, private independent international companies throughout the world. It is especially on-going and continued with every country that Saudi Aramco operates in. Some of these universities include the world's top: University of Cambridge, University of Oxford, Harvard University, MIT, and Stanford. He adds that Saudi Aramco works with many of these universities' calibre. Some of the oil companies include NOCs and IOCs of many countries in Europe, Russia, China, USA and Latin America.

P28 confirms that the communication between Aramco and other entities within the global oil and gas sector is very strong. For example, OPEC is one source of communication. Domestically, the MOPMR communicates well among other ministries and businesses.

P3 explains that Saudi Aramco has been there for 75 years even longer than the Ministry, so, the relationship between it and the MOPMR is relatively well-established. He also adds that the chairman of the board is the Minister himself. However, he argues that communication with other ministries is problematic and is very slow and bureaucratic.

⁴⁸ The joint industrial project (JIP) in pipe system manufacturing was created in 1998 to bring together manufacturers, users (such as Aramco) and testing institutes.

7.4.2 Technological development

P25 claims that the oil industry in Saudi Arabia embraces technology transfer and also migrate such technologies to others within the Kingdom. For example, the development of high severity FCC technology (Nipon Oil and KFUPM) demonstration at a refinery. He argues that this has been extremely successful, licensed to a commercial company and pre-commercial unit it has been developed in Japan. He adds that there is technology transfer from Japan, ACCENT France, Stone & Webster in USA.

P20 explains that Saudi Aramco has been at the forefront of utilising technologies, for example, establishing JV with Schlumberger that develops technology solutions and are leading high-tech companies. On the other hand, P18 argues that even though the oil and gas sector utilizes the state-of-the-art technology, however, most technologies are acquired rather than developed.

However, one of the participants gives an example of the first high-tech local company, the Saudi Arabian Television Manufacturing Company (Sat Jed)⁴⁹ which manufactures television sets, computer products and lately mobile phones in Saudi Arabia. One of its main features is to create products at competitive pricing. Sat Jed is the first local company to produce manufactured mobile phones and aims to releasing 2 million units in the market. Each unit, with built-in features to help the Islamic community follow praying practices, is priced at just over US \$100 [£62] per unit. The company invested US \$9 [£5.6] million to develop its own phone technology. It is important to note that Sat Jed is running its assembly plant in collaboration with Malaysia's Made-In-Malaysia (MIM).

7.5 Environmental Sustainability Direction

There are some efforts to raise awareness in electricity conservation, such as the programme launched by MOWE. All participants seem to understand the

⁴⁹ Source: <http://www.satjed.com.sa>

concept of sustainable development and the impacts of climate change, they all believe that Saudi Arabia must pursue sustainability while also support a strong economic development. However, P13 stresses that the Kingdom is not willing to pay more than its “fair share,” he argues that, for example, in the OECD⁵⁰ the oil product is heavily taxed while coal continues to be subsidized: *“We are not against protecting the environment, we are against the biasness and attaching different agendas to this noble cause of the environment”*.

In addition, P20 also agrees that it is necessary for Saudi Arabia to pursue sustainability but he argues that this means going beyond only ‘the environment’ and encompassing all the problems that we are facing in the economy, including: unemployment as well as maintaining a flexible system. P3 says *“sustainable development is a global imperative”* it is therefore imperative for Saudi Arabia as well, he explains.

Moreover, P20 explains that current environmental standards in the industry is very loose, for example, the cement industry is very polluting and inefficient, he adds that a quota has been levied on licenses to set up cement companies, now limited to ten, to protect the environment.

7.5.1 Driver towards sustainability

There are some international policies that act as drivers to pursue sustainability, argues P13. He gives an example of Clean Development Mechanism (CDM) and explains that it is one of Saudi Arabia’s drivers to open up its doors for investment in environmentally sustainable projects, he says: *“CDM is definitely a vehicle that will bring us more investment and a way to achieve economic development in a cleaner way”*.

In addition, P13 also adds that the Kingdom is considering options that will help in producing oil more efficiently and in a cleaner way. He argues that this is presented in CCS technologies, he states that *“since the world will still depend on fossil fuels for years to come, it is therefore crucial for Saudi*

⁵⁰ Organization for economic cooperation and development (OECD)

Arabia to consider cleaner production of oil, namely CCS". He adds that the world requires all sources of energy, renewable as well as fossil, but he argues that renewable energy sources will only contribute a small fraction to the world's total use of energy and asserts that the bulk of energy will still come from fossil fuels and therefore an only way to move forward is to invest in CCS.

Moreover, P18 argues that since the world's future direction seems to be geared towards 'sustainable development' this means that Saudi Arabia is put under pressure to act responsibly and also pursue cleaner paths to sustainability, this is because it produces and exports and holds the most oil in the world.

Furthermore, P18 describes Saudi Arabia's incentive to pursue cleaner energy as two-fold; (i) environmental obligations to reduce carbon dioxide emissions as well as maintain a good image in the world; and (ii) financial factor in saving more oil for exports and utilising solar energy for local energy production.

P17 adds another incentive for the Kingdom being a religious incentive, he explains that Islam conveys a message for Muslims to protect the environment, the subject is discussed in the textual sources, "*don't waste water, even if you were on a running stream*" (Hadith⁵¹); "*whales supplement prayers for humans that protect the environment*" (Hadith); Moreover, P23 agrees that our incentive is religious more than anything else, he recites the following verse from the Quran on the responsibility burdened by human beings to protect the environment: "*Indeed, we offered the Trust to the heavens and the earth and the mountains, and they declined to bear it and feared it; but man [undertook to] bear it. Indeed, he was unjust and ignorant*" (Quran 33:72).

⁵¹ Hadith refers to the second textual source of Islam, it is a collection of narrations by the Prophet (peace be upon him); the first textual source in Islam is the Holy book (Quran).

Similarly, P11 explains that there are a number of incentives and drivers for Saudi Arabia's need to embrace cleaner energy technologies, one is that Saudi Arabia is today the world's energy leader, second is that it has the world's largest oil reserves, and third is that there is a grand economic opportunity to invest and exploit cleaner energy technologies to continue to be the world's energy leader.

On the other hand, P3 argues that sustainable development also means to pursue 'economic sustainability', which means, he explains that in Saudi Arabia *"We need to make maximum economic benefit of our resources to maximise profit."* He elaborates that sometimes the concept of sustainable development becomes limited to considering the environment, however, in Saudi Arabia this means that 'carbon management' and namely CCS is *"the number one priority"*.

However, P23 explains that sustainable development means responsibility: *"we in Saudi Arabia should be the first to aim for it because it is part of our belief system and a principle of our religion"*. He adds, that this is attainable only if Saudi Arabia transforms it into an objective and *"not because other people are doing it, nor as a result of any regulatory framework, but because it is a principle of our religion"*. Moreover, P23 argues that there is no legal environmental pressures on Saudi Arabia because at the international arena there is no legal enforcer. However, he explains that there are moral commitments as well as responsibility that every country should pursue sustainability. In the long-run, P28 argues that the incentive is enlightened self-interest to serve as the world leading energy supplier whilst protecting the environment via producing and using oil in the cleanest way possible.

7.5.2 Policies

P13 states that Saudi Arabia is formulating policies to pursue a transition to a cleaner economy and explains that solar energy is estimated to be a major source of energy in the Kingdom, which will also help improve its efficiency

and conservation measures. Also, P1 adds that KACST has formulated its technology strategy in such a way that also tackles environmental problems.

In addition, P20 explains that sustainable development is a crucial part of the newly formulated national industrial strategy. He argues that the industry in the Kingdom is very young and this, he explains, presents opportunities to select carefully and utilise technology transfer.

Moreover, P18 states that Saudi Arabia has already formulated policies to ensure the protection of the environment and the development of future industrial projects. For example, SAGIA has launched four economic cities with strict international environmental standards. He also adds that KAEC has denied licensing to a number of factories (e.g. aluminium smelter) because they do not meet the environmental standards.

Similarly, P15 adds that there are strict environmental standards implemented in Jubail and Yunbu industrial cities, he explains that these standards are international benchmarks that were adopted by RCJY.

Furthermore, P15 points out two entities that are currently working on formulating environmental regulations, these are MOPMR and MEPA. These, P23 notes, are currently competing over who controls the carbon footprint as a national accounting body. But P26 explains that PME has been the only institution in the Kingdom that is dedicated for the environment. He argues though that although PME assesses how environment-friendly factories are across the industries, however, that are no government incentives for them to go cleaner.

7.5.3 Status of sustainability-related efforts

P3, senior at Aramco states: *“CM is there but I would put it as a priority number one”*. But P11 argues that Saudi Arabia *“should play it safe”* when it comes to announcing its efforts on CCS because he believes it is *“politically sensitive”*. He explains that CM is a shared responsibility and should not be

burdened by some countries only, especially developing countries, “*we must play it carefully and fairly*” he adds.

In addition, P26 explains that efforts in exploiting renewable energy in Saudi Arabia dates back to the 1970s when Sheikh Ahmad Zaki Yamani, then Saudi oil minister, founded KACST and initiated some solar energy projects in collaboration with Germany. The Solar City which was located in Riyadh developed some pilot projects that was running but the project had to end prematurely due to high costs, P26 explains, he emphasises that solar energy is imperative for the Kingdom today.

Moreover, P1 explains that MOWE is currently working on developing policies regarding the utilisation of alternative energy for electricity generation. He also argues that KACST continues to research solar energy and other cleaner energy technologies and aims to conduct technology transfer in this area. He adds that it is in KACST strategic goals to produce and develop solar cells technologies over the coming five years, the funding is from the government on a contractual basis. He explains that the incentive behind such an effort is to reduce local consumption of oil, however, the main challenge remains overcoming the relative high cost of renewables.

Furthermore, P1 adds that there are a number of academic and research centres that are researching the exploitation of renewable energy in the Kingdom. For example, KACST, KFUPM, and some related ministries. Current uses include, for example, ICT companies such as Saudi Telecom Company and Mobily Company, both utilise solar energy at telecommunication towers located in remote areas, for cathodic protection (to protect the pipes from rusting). Other uses include, solar cells being utilised to light canals in the south, and solar desalination in remote areas. He explains that these are all part of research efforts by KACST, which remains an R&D centre and not an electricity generation company. Actual application of solar energy must be led by the electricity sector and supported by government incentives to pursue the promotion of renewable energy in the country, he

explains. Similarly, P15 seems to agree on current efforts to exploit renewable energy as well as the need for a stronger political will and support.

In addition, P29 describes a new research collaboration being signed between KFUPM and MIT to oversee the centre of excellence at KFUPM to pursue clean energy and clean water research.

On the other hand, P9 believes that Saudi Arabia, with its vast oil reserves, does not really need CCS for enhanced oil recovery (EOR) but should apply it for the sake of the environment. He also argues that there is much sensitivity surrounding the term CCS in Saudi Arabia, which he explains is related to CCS-EOR that is typically carried out in 'mature fields,' which could [falsely] signal that Saudi Arabia is "running out of oil". A number of participants seem to agree with him.

Also, P11 believes that Saudi Arabia should to be a leader in CCS, current efforts he explains are not sufficient and public discourse tend to peak during conferences only. However, P11 explains that within the industry they seem to be researching it, yet, he believes the country must adopt it more vigorously.

To the contrary, P9 explains that Saudi Arabia plays an active role in CM as an active member at the carbon sequestration leadership forum (CSLF) and it has in fact hosted the bi-annual meeting of January 2008 in Khobar. It has also hosted other related events, such as the CDM Conference in Riyadh in September 2006, as well as the first regional CM Conference in Khobar in 2005.

In addition, P9 reminds that in the Oil Summit which took place in November 2007, King Abdullah of Saudi Arabia has pledged \$300 [£187] million for R&D in energy, environment and climate change. This money, he explains, is currently being translated into KAPSARC. The virtual operations are expected to start in 2009 and the building will be built by mid 2010.

Moreover, P9 adds that there are three research centres at Saudi Aramco that are currently working on CM from different dimensions: upstream,

downstream and policy and CDM issues. In addition, he explains that Saudi Aramco participates in developing CCS technologies through its funding of the Weyburn-Midale CO₂ project, the world's first CO₂ measuring, monitoring and verification initiative, Saudi Aramco has sponsored the entire project, its first phase 2000-2004 and its second phase 2005-2011.

Furthermore, P9 notes that although Aramco is only investing in R&D, yet it plans to exploit CCS projects in the future, in fact, it has also sponsored a number of projects and R&D activities with different international alliances and networks. For example, it sponsored CCS R&D in University of Regina on carbon capture from fixed sources.

For Saudi Arabia's future plans in CM, P9 states that it includes the focus on CO₂ industrial uses and carbon-based applications.

Moreover, P1 states that KACST is undertaking clean energy research including research on advancing internal combustion engine to reduce pollutions and improve fuel economy, as well as research on fuel cell and hydrogen fuel cell.

On the quest to balance between the collective responsibility to care for the environment, and at the same time, the obligation to sustain growth for the global economy, Al-Naimi in the energy pact conference in March 16, 2009 emphasises: *"... We must acknowledge that fossil fuels will serve these needs [energy demands] for decades to come, our immediate focus, then must be to make fossil fuels cleaner and more efficient"*.

An initiative for initiating research on cleaner energy technologies and policies [at the time of the interview] in 2008/09 is the establishment of KAPSARC, which was then at the conceptual phase:

King Abdullah Petroleum Studies and Research Centre (KAPSARC):

KAPSARC is a future centre for energy, environmental research and policy studies. Its vision includes advancing Saudi Arabia's role as the premier, environmentally-responsible supplier of energy with research areas focused

on energy markets and policy, energy and environmental technology, and energy data and modelling, amongst other related areas.

P28 informs that KAPSARC is still being developed conceptually and will only be out in the public in 2010, it will be located in the capital, Riyadh, it is in MOPMR's aspiration to have this as an iconic centre that is consistent with the vision that Saudi Arabia as *"the world's largest energy supplier that protects the environment"* P28 says. However, some challenges that KAPSARC is currently facing are *"very high"* given the social norms and scarcity of high-level researchers within the Kingdom. Today, the development team, who P28 notes are mostly from Aramco, are in the process of attracting high-calibre researchers.

In addition, P28 quotes in a recent energy pact conference that took place in March 16, 2009, HE oil minister Mr. Al-Naimi mentioned KAPSARC as a future think tank whose aim will be *"supporting reliable energy supplies to sustain the world's economic prosperity and growth and fostering our role as an environmentally responsible energy supplier"*.

Furthermore, P28 explains that KAPSARC development team works directly with MOPMR and Aramco on designing a pilot project in the next 2-3 yrs at a demonstration scale for CCS-EOR.

Status of Environmental Negotiations

On environmental negotiations, P9 explains that Saudi Arabia is supportive of the Bali Roadmap that has been created to supersede the Kyoto Protocol that expires in 2012, being also a signatory to the latter as an Annex II⁵² country. He argues that Saudi Arabia is dedicated to pursue this roadmap in the long-term, however, he stresses that this has to be done *without* obliging itself (or its OPEC members and regional neighbours) to any legal frameworks. P9 adds: *"there are talks and negotiations taking place to include some oil-*

⁵² Annex II countries under the Kyoto Protocol are "developing countries not required to reduce emission levels unless developed countries supply enough funding and technology"

producing developing countries in Annex I⁵³ countries to be obliged to cut their carbon emissions. Subsequently, Saudi Arabia and OPEC formed alliances to make sure this will not happen". He believes that politics play a role in environmental negotiations: "there are 140 developing countries and it is impossible for them to meet these environmental targets, so this will be an excuse for developed countries, developing countries are asking for financial support and developed countries refuse to grant them that – there are many issues to this..". Furthermore, P9 gives an example of steering negotiations towards national interests: "While Brazil is not keen on including CCS as a cleaning technology and part of the carbon credits mechanisms, they are exploiting biofuels for get carbon credits. Similarly, Saudi Arabia does not have interest in including forestation as a mitigation option but Brazil does, we don't have the same interests", he explains.

P11 argues that in the oil industry's defence, only portion of the global carbon emission is the responsibility of the oil sector, however, there are many other sources of carbon that are not being heatedly debated in the public. For this reason, he believes that due to political factors, Saudi Arabia is concerned about its picture and will act accordingly.

7.5.4 Vision, policies and efforts for sustainability

This final section from interviews results presents the Kingdom's status in terms of its efforts towards sustainability including vision, policies and efforts for sustainability.

In 1975, Saudi Arabia's flared gas in the oil and gas industry was converted from waste to value, the same strategy could be applied to convert 'wasteful' carbon into valuable and useful feedstock for the petrochemical industry, argues P24.

⁵³ Annex I countries under the Kyoto Protocol are "developed countries who ratified the Protocol and have committed to reduce their emission levels of greenhouse gasses to targets that are mainly set below their 1990 levels"

On the other hand, P15 explains that despite Saudi Aramco's business focus on the oil and gas industry, it further considers clean energy mechanisms such as CCS-EOR, which is evident in their active inclusion of the technology in their R&D portfolio. This direction, he argues, is important for Saudi Arabia as it gives it a slightly increased role internationally and reflects a more desirable image of the responsibility for the environment.

In terms of future direction, P1 explains that the work of KACST strategic plan works towards sustainability – it includes plans for renewable energy, hydrogen and improving energy generation, also, KACST is the Kingdom's leading effort in developing STNP.

The Saudi National Industrial Strategy (SNIS):

The SNIS envisions Saudi Arabia to be "a globally competitive industry, based on innovation and acting as a major tool in transforming national resources into sustainable wealth" and its '2020 strategic goal' is "to increase the contribution of the manufacturing sector to the GDP to 20% by 2020 from the current 11%".

The plan is an initiative by MOCI to track the national economy of Saudi Arabia and immune it from the volatility of the oil market, says P20. He explains that this is due to the fact that the GDP and oil prices are very much linked and this is evident in the past trends of the GDP, which has been heavily impacted by the oil prices. Therefore, it is in the SNIS's vision to diversify the economy.

P20 adds that by 2020 the workforce based on our population distribution will require 3.8 million additional jobs. This is for young Saudi men and women who will not accept low pay jobs. This means that the jobs must meet high calibre workforce.

The strategy is a joint-effort between MOCI and UNIDO, there is also an expert team that form the senior committee comprising of 30 people, half of which is from the government sector and the other half is from the private

sector. Before publishing it, the document was viewed and ratified by both SEC and the Council of Ministers.

P16 explains that part of KACST's responsibilities is to supervise and prepare in collaboration with the MEP and the STNP, which was approved in 2003. It has a 2020 Vision – to be implemented over 4-5 years. The first 5 years plan is to establish the infrastructure for science and technology; the second is to make Saudi Arabia the regional leader in science and technology; the third, to be a hub and one of the leaders of science and technology in Asia; the fourth, to reach knowledge-based society and economy.

The STNP funding, explains P16, amounts to SR 8 [£1.33] billion allocated over five years. This research funding is equivalent to the double of what was spent on KACST since its inception over 30 years ago which amounts to a total of \$400 [£250] million.

P14 mentions that KACST has recently started the NIE project, which identifies the country's strengths and weaknesses.

The principles and bases of the STNP is *“based upon the teachings, values and principles of Islam that encourage learning, education and perfection of work. The Plan also draws upon the Arab and Islamic cultural heritage”*⁵⁴.

National Science and Technology Policy (NSTIP)

The NSTIP history find its roots in the establishment of KACST as the national research lab in 1986 with a purpose to *“propose a national policy for the development of science and technology and to devise the strategy and plans necessary to implement them”*. In 2002, the NSTIP was launched in collaboration with MEP to develop a long-term national policy for science, technology and innovation, part of which is the recently formulated National Science, Technology and Innovation Plan and the National Innovation

⁵⁴ KASCT - STNP Principles and Bases, source: www.kacst.edu.sa/en/about/stnp/pages/principles.aspx

Ecosystem (KACST 2011), these are being formulated by SRI international consultant firm. The following diagram provides a scheme of the plan:

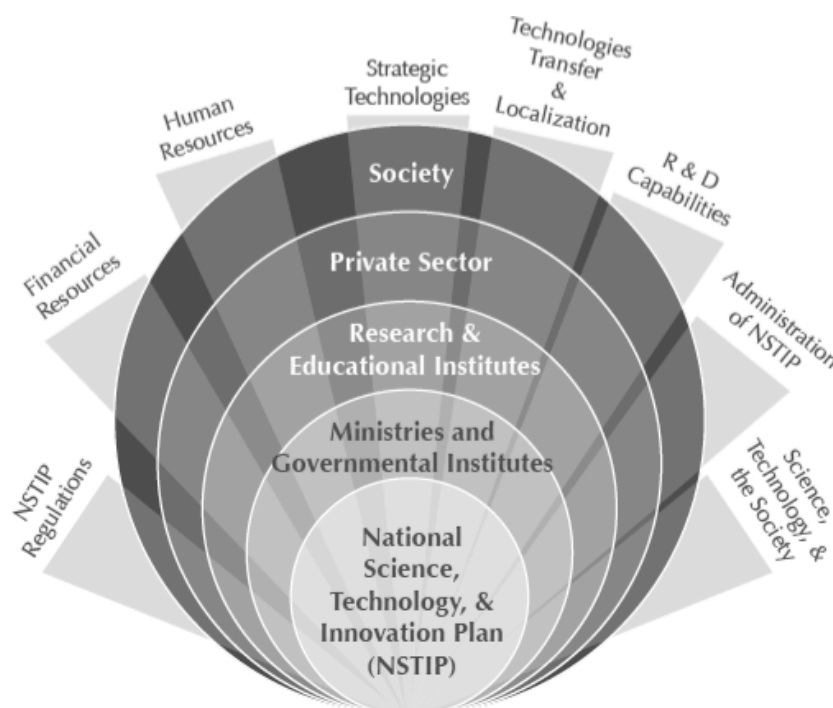


Figure 7-1 Science and Technology Plan (Source: KACST 2011)

Figure 7-1 shows the science and technology plan developed by KACST via SRI international consultant firm. The national science, technology and innovation plan (NSTIP) is placed at the heart of the plan and involves a number of actor-networks across the Saudi NSI, ministries and governmental institutes, research and educational institutes, the private sector and the society. Other roles are also highlighted, including: NSTIP regulations, financial resources, human resources, strategic technologies, technology transfer and localization, R&D capabilities, administration of NSTIP, and science, technology and the society. This is a similar undertaking to the one that has been developed in this dissertation. The above diagram however is abstract and does not reflect the particular structure of the Kingdom's economy. This general framework acts as a guidance to what must follow next of policy-making processes whose outcome should ideally produce a *Saudi sustainable innovation policy*.

Saudi Economic Cities

There are four economic cities projects that have been launched: (1) King Abdullah Economic City (KAEC) in Rabigh, the first to be operating in 2009, and the entire city is 160,000 km² with 2 million population capacity. (2) Medina, (3) Hail and (4) Jazan. They could be said to be 'sustainable' cities because they are using 'green' building concepts, P18 explains.

P18 believes that the economic cities will play a major role in promoting innovation, as it will offer an environment that encourages technology innovation. For example, he explains, by building an ICT infrastructure that competes with the world's finest and having a full coverage of Internet at 100 MB per second; citizens are exposed to the latest technological advancement in Internet use. This will offer them a better lifestyles and most importantly to drive innovation. KAEC attracted world-class R&D centres, there is also a recent contract signed with KACST to enable and stimulate innovation. He adds that there are four factors that are forming the backbone of economic cities: (i) Human technical skills, (ii) Technical training, (iii) Educational system, and (iv) Incentive for local R&D.

The National Energy Efficiency Program (NEEP):

P1 explains that NEEP is a group of organisations, ministries and companies within Saudi Arabia working towards the objective of energy efficiency. SECO is participating in this effort, the programme has been working for five years to introduce these efforts

Saudi Clusters

The Saudi Clusters is a joint program between the MOPMR and MCI. P20 explains that the focus of Saudi Clusters is going to be multi-faceted and will definitely spur innovation in the economy, such focus will for example include: technical know-how, technical ability to disseminate knowledge, management and training particularly for SMEs, R&D and soft skills.

National Innovation Eco-System (NIE):

The project comes as part of the KCAST-led NSTP and a collaboration with Al-Aghar Group. The focus team is composed of the top thinkers in the Kingdom who meets regularly to formulate the vision, mission and objectives of the project. The NIE project complement the objective of the Saudi government, which is to become a Knowledge-based Economy by 1444 H (2023 G). P22 explains that the term 'ecosystem' is borrowed from the biology discipline and reflects a more precise term for the complexity of such a system in the Kingdom.

However, P18 believes that current efforts are only conceptual and includes formulating a plan rather than a project, "*the plan is being developed as we speak*" he explains. Moreover, P10 says that the NIE project is being managed by KACST, their main objective is trying to create a roadmap, "*it is still in the work-in-process*". She also explains the methodology of the undertaking involving a group of people who form the 'think tank' for this project and are invited to meet regularly to draft their input and views on how to improve it. P10, who is one of the members says: "*We already got an approval on the budget, as well as building a strategic partnership with global networks*".

In addition, P4, another member to the group, believes that the components of the NIE must work together. He explains that there are different types of components: (i) 'producing' components, these are the organizations that produce innovation e.g. the private sector and the industry; (ii) fostering components, these are the organisations that support and foster innovation and (iii) feeding components, these are the organisations that provide funding and facilitate interactions.

7.6 Summarising Contributions

There are a number of critical issues that were presented in this chapter which informed the Saudi NSI through: (1) identification of the major forces

that make up the *agents* across the Saudi NSI, (2) understanding the relationships and networks that underlie these agents, (3) summarising recent efforts that deals with [environmental] sustainability and innovation in the Kingdom, (4) summarising such efforts with a focus on the oil and gas and energy sector and the prospects of pursuing cleaner energy, and (5) exploring future directions communicated by main agents in the Saudi NSI. This final section summarises the results and draw some conclusions in the form of 7.6.1. Themes from empirical findings, and 7.6.2. theoretical inputs from empirical findings, 7.6.3 Articulating the Saudi NSI.

7.6.1. Themes from empirical findings:

1. Bureaucracy seems to be a reoccurring theme emerging from the results, bureaucracy as characterised by time-consuming tasks and inefficient processes that hinders the processes of effective communications between and within the agents.
2. Lack of an overarching aim that defines the direction set by the government and embraced by other agents across the economy.
3. Environmental flexibility: Environmental concerns and standards are not regarded as a priority and therefore a political will is needed.
4. Lack of an industrial base: There seems to be a consensus that Saudi Arabia is not an industrial base economy in its manufacturing sense and therefore does not generate 'technological innovation' but rather is heavily dependent on a resource, and has created an economy around it.
5. Importance of 'self-image' in the world A number of participants reiterate that Saudi Arabia regards itself as the world's provider of energy and holds itself as responsible and committed in keeping its image unstained. This is evident in the issue of CCS-EOR and oil depletion that builds politics around the endeavour as discussed before.

6. Lack of institutional structures that facilitate communication between NSI agents, and relying on classic paperwork without using the Internet to speed up communication.
7. Outsourcing/Buying technological innovation and buying latest technologies from abroad even in strategic technologies such as the oil and gas and energy sector.
8. Lack of patent office / intellectual property laws services that is particularly hindered by ineffective structure and time-consuming bureaucratic procedures.
9. Current lagging in technological innovation is commonly present in every sector in Saudi's NSI, participants seem to describe it as a 'façade' rather than producing real results.
10. Education system which reflects the quality of the national human capital that forms the basis of innovations in NSI, it has been criticised as being not up to the standards, or deteriorating as some participants see.
11. R&D activity is limited to companies and their individual incentives and lacks guidance from a vision by the government.
12. Lack of clear structure in ministries: overlapping responsibilities between ministries that cause repetition of work, lack of structured communication, which resort to creating ad-hoc committees for every project.
13. Culture of competition rather than a culture of complementary, supportive and interdependent nature.
14. Resourceful funding with lack of project supervision there seems to be a challenge even with the resourceful nature of new projects, a common concern that defined funded-projects is the lack of supervision and enforcement of regulations against corruption.

7.6.2. Theoretical inputs from empirical findings:

- Sustainability approach: Religion [of Islam] as a possible source for driving sustainability, especially environmental sustainability and especially in a religious state, such as Saudi Arabia.
- Innovation process: The key role of international networks [embodied in international organisations, international consultant firms and international corporations] for directing, managing and stimulating technological innovation and national competitiveness through international corporations and subsidiaries, joint venture, FDI, consultancy work and various joint-projects.
- NSI agents typology: (1) ‘producing’ agents are those who produce innovation such as the private sector and industrial pillars; (2) ‘fostering’ agents that foster innovation for raising human capital and enriching R&D intensity in organizations such as education system, SMEs incubators, clusters, innovation-stimulating institutions like Mawhiba; and (3) ‘feeding’ agents are those that provide funding, research and facilitate a platform for NSI such as the financial system, research centres and governance structure.
- NSI connectedness: Ad-hoc committees as facilitators for inter-linkages across NSI agents, royal decrees and commissions as fast policymaking.
- Overarching aim: in centrally-planned governments, enforcing an overarching aim to stimulate strategic directions could be utilised to implement faster results.

7.6.3. Articulating the Saudi NSI

Figure 7-2 shows the structure of the Saudi NSI based on the findings from this chapter but also incorporating it with the literature reviewed in previous chapters; these have been classified into eight *sub-systems* within the Saudi NSI that directly impact and define ‘innovative capacity’ in the Kingdom: government, institutions, industrial pillars, market, research, and education. In this section, a discussion of these sub-systems is provided in light of the findings and themes developed in the previous section and also providing a comparison with other relevant studies in the literature.

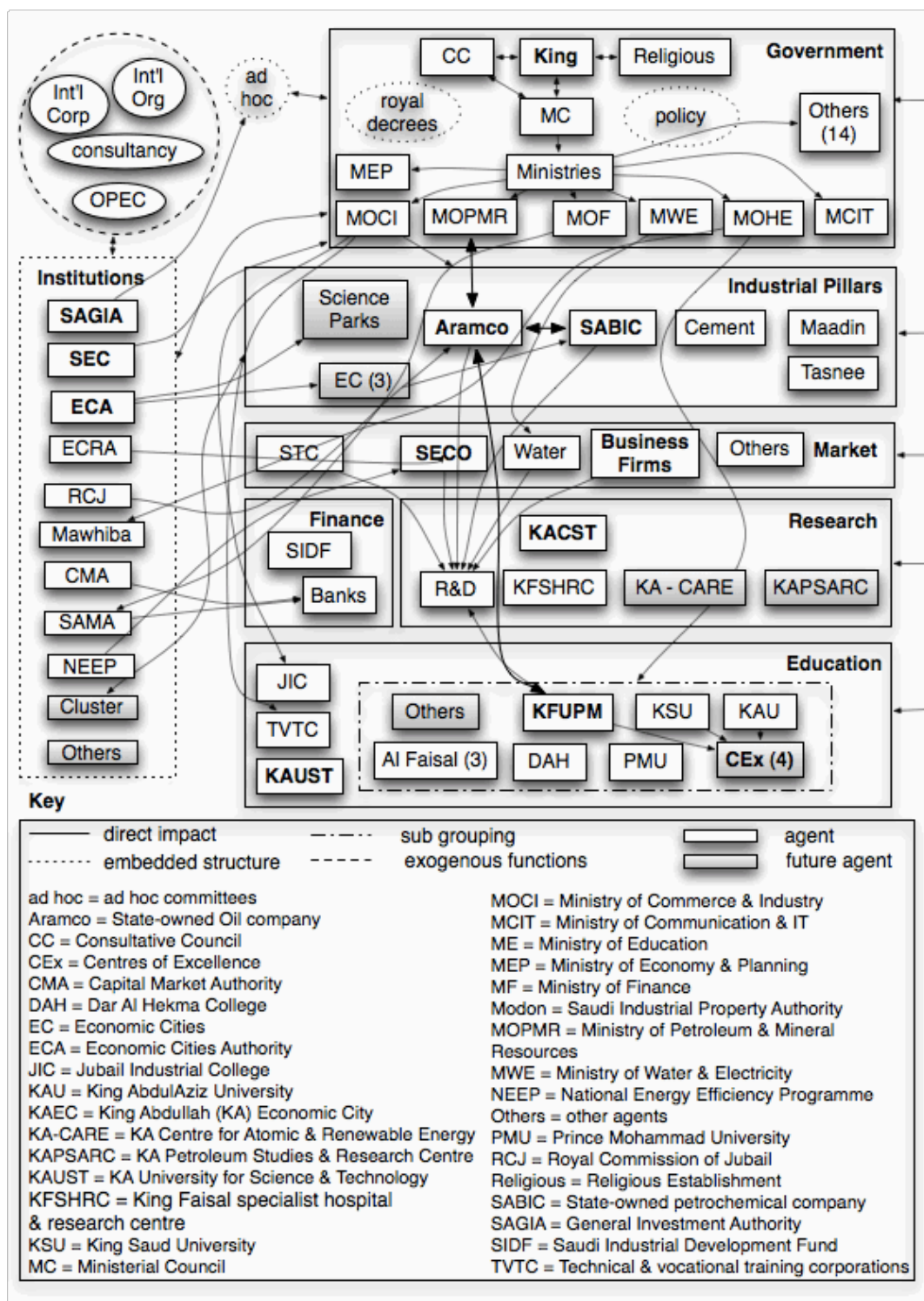


Figure 7-2 The Saudi National System of Innovation (Source: Author)

1. Government

The Saudi government structure is largely centralised, major decision-making and policy-making are carried out by the king, the ultimate top authority; a

main policy tool provided by the king is the royal decrees. Followed by three agents: (i) the council of ministers, this is a representative council for all the ministries, (ii) the consultative council, which provides consultation and approves laws and regulations via the line of command, and (iii) the religious establishment, this is an independent party that maintains a fairly powerful role in policy-making by advising the king and assuring laws and regulations are conforming with Islamic law. Ministries are represented in the ministerial council and it is where major decision-making for every ministry is conducted. Royal decrees and policy are represented as embedded structure in the government sphere; these are the outcome of different interactions between different government agents. To overcome the highly bureaucratic structure, 'fast track' decision-making or 'quick-fix' policies like the creation of ad-hoc committees and the issuance of royal decrees are ways of dealing with strategic issues. Main ministries are placed under the MC, these include: MEP, MCI, MOM, MF, MWE, ME and MCIT and (14) other ministries. Bold line represent 'direct impact' which shows some relationships that connect the government with institutions as well as other entities, industrial pillars, market, research and education entities.

There are apparent weaknesses with the structure of the government which could challenge the fulfilment of Saudi's NSI, for example, the bureaucratic structure of the government, although exercises stronger leadership and authority but lacks effective management and competent overall supervision, this tends to create obstacles and slow down processes that will ultimately induce innovation.

2. Institutions

Institutions in Saudi Arabia presented in the diagram are the agents that provide regulation, management, control and decision-making to various functions of the economy. The institutions entity is indicated by dotted lines that indicate an 'embedded structure' in the economy.

The main institutions in the Kingdom are presented in the diagram: SAGIA,

SEC, ECA, ECRA, RCJ, Mawhiba, CMA, SAMA, NEEP, Cluster and others. These institutions have been discussed earlier in the chapter, all of which form the agents that regulate, manage and control activities and processes in the economy that supports and spurs innovation.

3. Industrial Pillars

The backbone of the Saudi economy is manifested in the industrial pillars that have long contributed to economic development in the Kingdom. The main industrial pillars that are presented include the two main pillars (emphasised) Aramco and SABIC, others include Cement industry, Maadin, Tasnee and future science parks as well as economic cities – these future agents are indicated by grey boxes. Agents under industrial pillars are connected to government, institutions, research and other agents, the lines indicated ‘direct impact’ between agents, for example, a line between Aramco and R&D centres under research indicate a relationship and contribution for research by Aramco.

4. Market

Market in Saudi Arabia is represented by a number of agents that provide a platform where the society engages as consumers and clients of the NSI. These include STC, SECO, Water sector, business firms, and others. Companies’ innovative activities contribute to the account of innovativeness in Saudi Arabia. More particularly, international firms that train and provide latest products and processes contribute to enlarging the innovative capacity.

Figure 7-3 shows the top 100 Saudi companies by sector (2006) which gives an overview on the market structure:

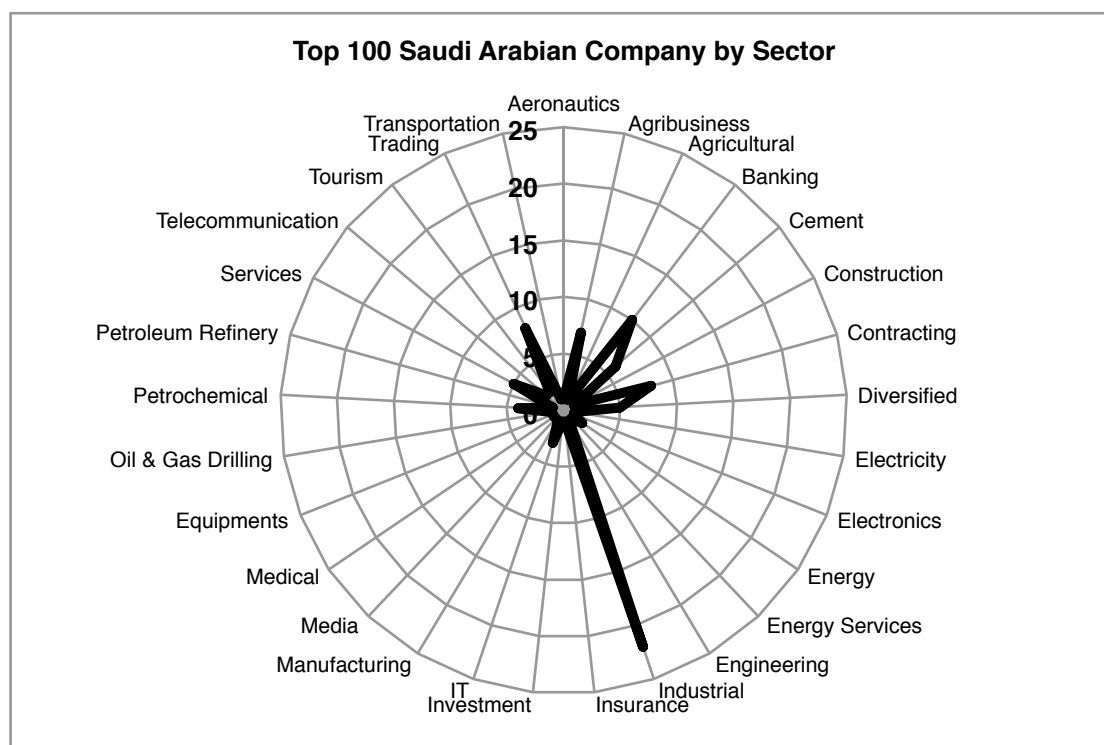


Figure 7-3 Top 100 Saudi Arabian Companies in 2006 by Sector (Data source: Saudi Directory 2006)

The figure shows an account of the top 100 Saudi companies, according to Saudi Directory (2006), in the three main cities in Saudi Arabia: Riyadh, Jeddah, Dammam and Al Khobar. The ranking is done by market value of the company. Here, a radar chart is plotted to show companies by sectors. *Industrial* sector ranked highest at 22 companies, next is the banking sector, followed by trading, contracting, agribusiness, and other sectors. Business activities in the market as well as the movement of supply and demand contribute to the innovativeness capacity in the Kingdom.

5. Research

Research activities in the Kingdom is represented by main bodies including the government lab KACST (emphasised), the health sector, and R&D agents which include the different R&D centres in the main firms and industries that underlie the Saudi economy: Saudi Aramco in the oil industry, SABIC in the

petrochemical industry, SECO in the energy sector, water desalination sector. The health sector is treated as an independent agent for it provides R&D for medical purposes and does contribute to the account of innovative capacity by employing the latest technologies and innovation in the medical field. Other bodies under research include future KACARE and KAPSARC.

6. Education

Educational institutions are presented in the 'education' entity with a subgroup of universities and colleges. The main institutions that are under ME includes: KFUPM (emphasised), KSU, KAAU, Al Faisal three institutions, DAH, PMU, and the four centres of excellence under KFUPM. Other institutions include JIC, TVTC and KAUST (emphasised).

Education in Saudi Arabia is constantly changing and effort to reform continues to provide a promising outlook. Education for women has only started in 1960, 30 years after the creation of modern Saudi Arabia. It continues to be a 'battle ground' between the religious conservatives and the liberal reformists. Even decisions to include more science subjects can be perceived as reducing the school hours for religious subjects. Traditional and religious forces continue to shape the nature of the subjects, for example, KFUPM the leading university for petroleum studies only. As has been discussed, the Kingdom is taking a direction towards reforming education, the spending by percentage of GDP is shown below:

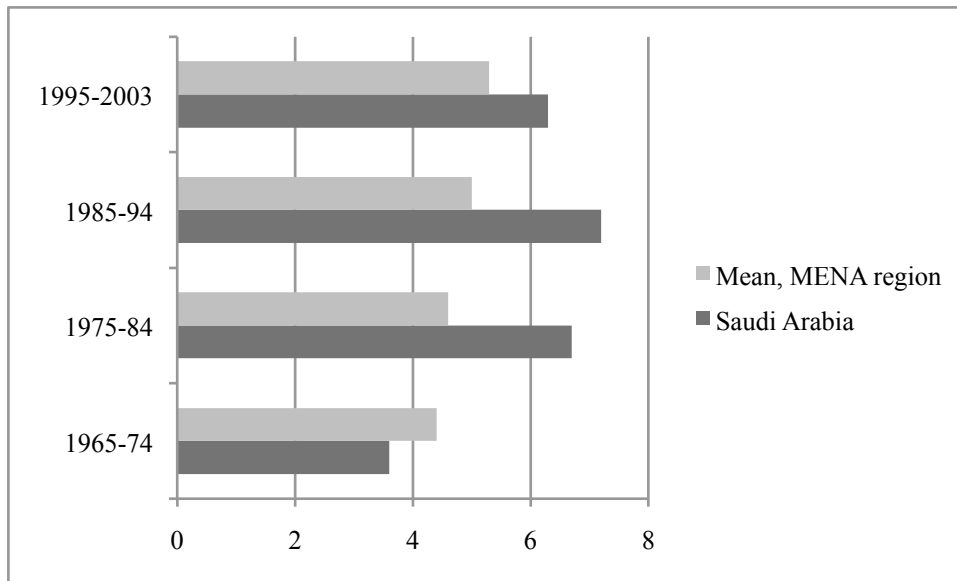


Figure 7-4 Average of public expenditure in education as a percentage of GDP in Saudi Arabia compared to the mean average in Middle East and North Africa between 1965-2003 (Data source: World Bank 2008)

The quality of secondary education is an important indicator of human capital performance in developing countries. Trends in International Math and Science Study (TIMSS) is used as an indicator. According to the World Bank report (2008, p. 19), average test scores of TIMSS taken in 2003 by secondary students, Saudi Arabia resulted in approximate average test score of 332, the lowest of all scores. The mean average of MENA region is 399, in Asia 467, in Latin America 408, international average is 489, top performing country is 617. Despite its very high GDP/capita of 12,495 the low score of maths shows Saudi Arabia's human capital performance is considerably low.

The distribution of university students by field of study in Saudi Arabia is shown below with a striking low number in scientific, technical and engineering (STE) field. In order for the national human capital to be upgraded to a level that will support innovative capacity in Saudi's NSI, more intake in the STE field need to take place, as well as more institutions that offer such fields.

Distribution of University Students by Field of Study, %

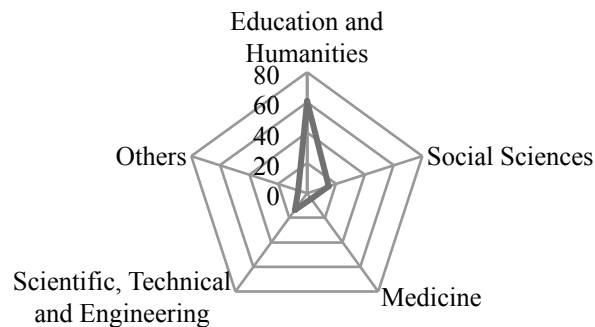


Figure 7-5 Distribution of University Students by Field of Study in Saudi Arabia in 2003 by Author (Data source: World Bank 2008)

Illiteracy Rates of the Population Aged 15 and over by Gender

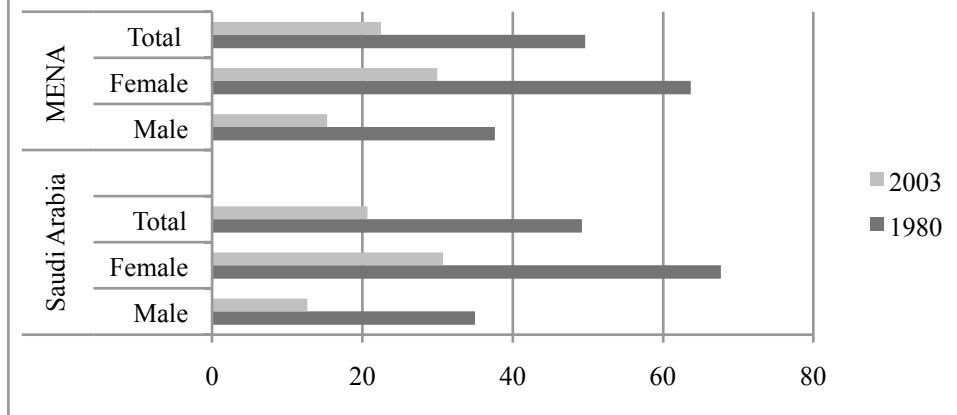


Figure 7-6 Illiteracy rates of the population aged 15 and over by gender in Saudi Arabia, comparing 1980 and 2003 by Author (Data source: World Bank 2008)

The figure 7-6 shows the illiteracy rates of the Saudi population compared to that in the MENA region, showing the total number by percentage and by gender. There is a notable difference from 1980 to 2003, particularly in female literacy dropping from 70 to 30%, and overall from 50% to 20% in the overall economy. The percentage of 20% is still very high, and this is one of the challenges that remain present in the Kingdom.

As discussed earlier, education in Saudi Arabia is entering a new era, a number of new initiatives have recently been introduced to upgrade the system of education, these include: (i) King Abdullah Foreign Scholarships Program for abroad study worth more than SR 7 (£1.2) billion for college and university education in prestigious universities in USA, Britain, Germany, Canada, Japan amongst other countries, it was founded in 2004, there are over 7,500 students currently undertaken their studies; (ii) National Centre for Assessment in Higher Education (Qiyas), which aims to provide assessment tests for high (tertiary) school, scores are used as indicators for scholarship applicants at King Abdullah Foreign Scholarships Program; (iii) national commission for academic accreditation and assessment (NCAAA) developed to assess and accredit all post-secondary education institutions and programmes in the Kingdom. Indicators includes: in-house assessment, alignment with national framework for qualification, complying with quality measures of the programme, student management, institution management, and faculty management; (iv) national centre for E-learning and distance learning project at its preparatory stage that aims to facilitate and streamline collaborative efforts in higher education organizations to utilise electronic learning applications. Other efforts are taking place and under planning such as the creation of higher education statistics unit to track records and create an archive system for past data; and geographic information systems project to link geographic information of all higher education institutions with the rest of urban program.

Moreover, the establishment of its first science and technology university (KAUST) and the building blocks for funded R&D in CM technologies (KAPSARC). Investment in education systems reflect the level of human capital, figure 2 shows a comparison between Saudi Arabia's spending on education as a percentage of its GDP and that of the Middle East and North Africa (MENA)⁵⁵ region.

7. Finance

The financial system in Saudi Arabia is governed by two institutions, ECA and MOF. The figure below shows the performance of companies in the financial market which is a reflection of the activities by each sector in the economy and the value of that. The top three sectors are (1) petrochemical industries at 25%; (2) Banks and financial services at 22%, (3) telecommunications and information technology at 11%. This is presented in the pie chart from figure 7-7.

⁵⁵ The MENA region comprise of Algeria, Bahrain, Djibouti, Egypt, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates, West Bank and Gaza, and Yemen.

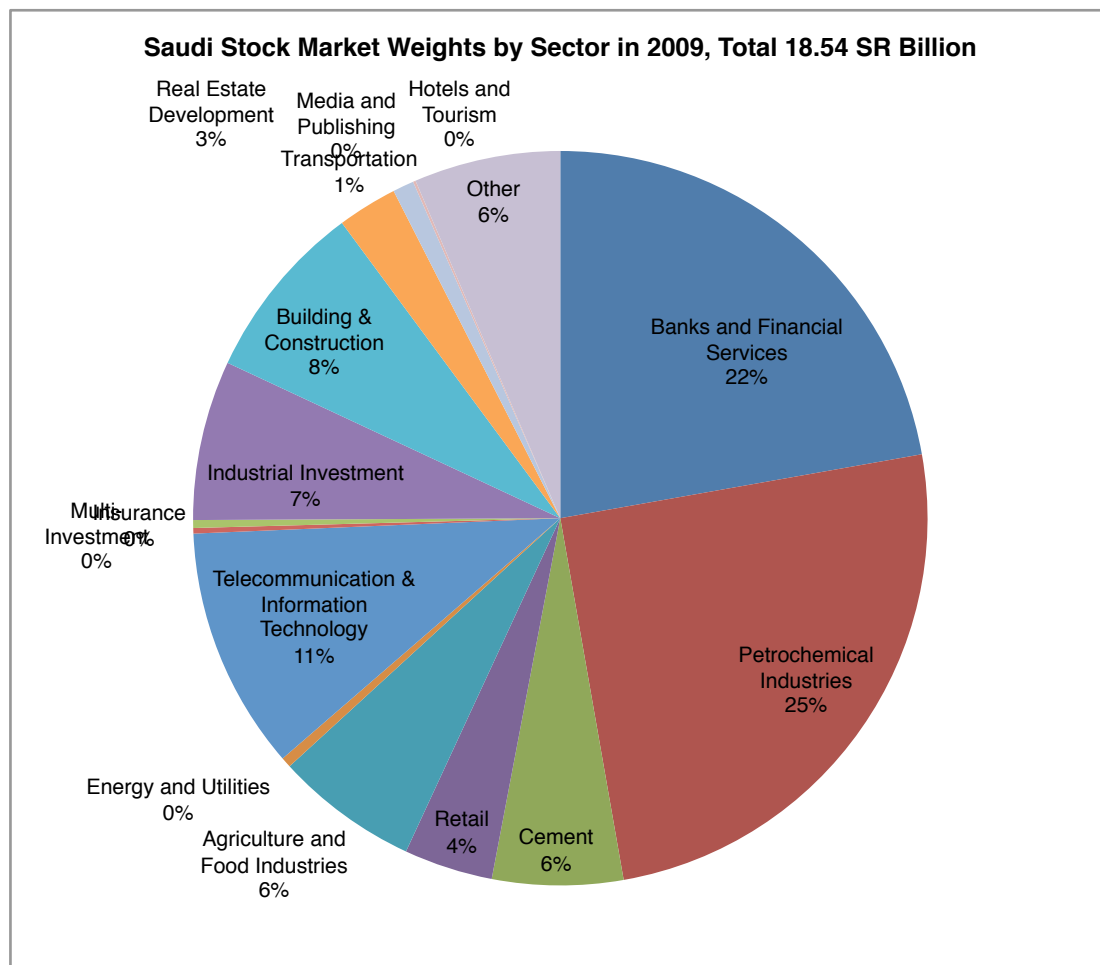


Figure 7-7 Saudi Stock Market Weights by Sector in 2009 (Data source: CMA 2009)

8. Exogenous functions

Exogenous functions are provided by external agents and indicated by the dashed line in the diagram 7-1. They play a major role in economic development in Saudi Arabia by signing agreements, MOUs, laws and regulations. External agents include international organizations, international corporations, international consultant firms, and other organizations at the supra-national level such as OPEC.

- International organizations (Int'l Org) play a key role in advancements of science, technology and innovation in developing countries, mainly through its advisory service. The World Bank (WB), for example, cooperate with Saudi Arabia via the Technical Cooperation Programme (TCP) which works on various areas of development such as large infrastructure projects (transport

and urban development) and also include in the future water supply, health, transport, environmental issues and private sector development⁵⁶.

- International Corporations include all the affiliates in Saudi Arabia that bring training, knowledge, and assist in the technology transfer process from their international subsidiary group.
- International Consultancy Firms, these include Stanford Research Institute (SRI), Charles River Associates (CRA), Michael Porter (competitiveness forum), Malaysian government (NIE); who participate in economic development by advising and guiding major development projects.
- OPEC provides a platform for Saudi Arabia to exercise its power as a major oil producer, it helps institutionalise regulations that attempt to manage oil pricing and trade.

9. Other Key Actors and Activities in the Saudi NSI

1. *Foreign direct investment* managed and stimulated by SAGIA is regarded as a major factor in transferring technologies from home countries (of international subsidiaries) and therefore assist in the creation of a human capital for developing the building blocks of NSI.

2. *Indigenous firms* in the Saudi NSI are those *national champion firms* (see Chapter 4) are Saudi Aramco and SABIC – both serve strategic sectors for Saudi Arabia and receive considerable state support. Table 7-2, compiled by Porter (2011), shows the top Saudi Arabian organizations that register patents between 2005-2009. These are the indigenous firms for the Saudi NSI. This also goes along the findings from the interviews and were plotted in the Saudi NSI diagram.

The table shows an important indicator for Saudi Arabia's innovativeness capacity using the patents benchmark. Porter (2011) compiles the total number of patents registered in UPSTO between 2005-2009, by organization.

⁵⁶ World Bank.Org, 2011 "Gulf Countries – Saudi Arabia" <http://go.worldbank.org/53Y1H0UPC0>

Table 7-2 Top Saudi Organisations in Patents Registration (Source: UPTSO2 010 in Porter 2011)

Organization	2005	2006	2007	2008	2009	Total
Saudi Arabian Oil Company	12	5	10	20	8	55
Saudi Basic Industries Corporation	3	7	3	3	1	17
King Fahd University Of Petroleum And Minerals, Research Institute	1	0	1	2	8	12
Other organizations	1	1	4	3	4	13
Individually Owned Patents	1	6	2	2	1	12
Total Saudi Utility Patents	18	19	20	30	22	109

The main players in the Saudi economy contributing to its innovative capacity is expectedly its strategic oil sector and its closely-related petrochemical company and petroleum university. Saudi Aramco, SABIC, and KFUPM. Other patents are scattered between different organizations and individuals.

3. Private Sector

The private sector is important in contributing to support innovative activities in Saudi's NSI, the private sector's contribution to GDP in Saudi Arabia in the early 2000s account for 40% (World Bank 2005).

An example from the private sector is Bab Rizq Jameel is a private initiative that was established to assist in raising the employment rate in Saudi Arabia. Since its establishment and through various programmes it has achieved 14,276 beneficiaries from its training programmes, and 18,593 beneficiaries from its direct recruitment programme.

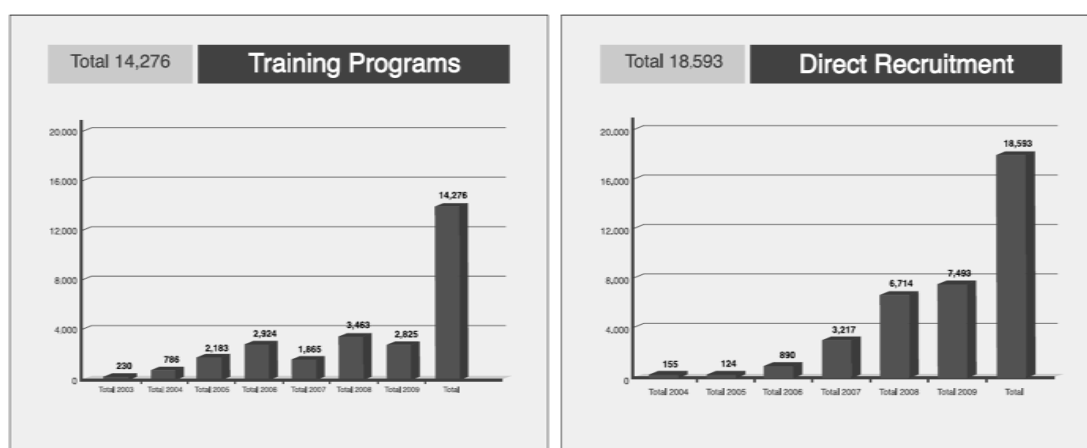


Figure 7-8 Private Sector Initiative Bab Rizq Jameel Job and training creation (Source: 2009)

Comparing the findings from this chapter to a summary that was developed in the eighth development plan (EDP), Saudi Arabia places itself in the building blocks of a knowledge-based economy. The following box shows the main projects that support such an aspiration:

Most Important Supporting Projects for Building a Knowledge-Based Economy:

1. Economic cities under the Saudi Arabia General Investment Authority (SAGIA), namely:
2. The Technology Zone in Dammam (Modon - Saudi Organization for Industrial Estates and Technology Zones).
3. The ICT Park in Riyadh (High Commission for the Development of Riyadh)
4. Industrial Zones Projects that will be set up in various regions of the Kingdom to implement the Programmes of the National Industrial Strategy.
5. The Governmental Electronic Transactions Programme (Yasser).
6. The Riyadh Techno Valley and the Oasis of Knowledge, within the Knowledge Centre Programme and the Knowledge Corridor Programme (Ruwaq) at King Saud University.
7. King Abdullah University of Science and Technology (KAUST)
8. King Abdullah Scholarship Programme.
9. King Abdullah Programme for Development of Education.
10. King Abdullah Initiative for Arabic Digital Content.
11. King Abdullah Financial District in Riyadh.

Source: Box 5.1 Pg. 94 The Ninth Development Plan, Saudi Arabian Ministry of Planning and Economy (2010)

Conclusion

In conclusion, the empirical findings from the interview research have informed the materialisation of the Saudi NSI in this chapter. This will be incorporated in the next chapter as a foundation for a transition towards a sustainable carbon management system of innovation.

8 A Sustainable Carbon Management ‘System of Innovation’:

A Proposed Approach for Saudi Arabia

This chapter discusses the transition in the Saudi Arabian ‘national system of innovation’; it brings together the findings, analysis and discussion in the dissertation to a new level. Using progressive knowledge gained from previous chapters from the literature review in chapters two and three, on the subjects of climate change, the economy and energy sector of Saudi Arabia; the theoretical frameworks in chapter four; the portfolio of carbon management technologies in chapter five; the LCA study on CCS and Solar PV in chapter six; and the results from research interviews conducted for materializing the Saudi NSI in chapter seven. This chapter presents a sustainable carbon management ‘system of innovation’ as a proposed approach for Saudi Arabia.

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 - 8.3.3 Knowledge diffusion (F3) - Score 2
 - 8.3.4 Guidance of the search (expectations, visions, policy goals, customer demands, selection) (F4) 3
 - 8.3.5 Market formation (niche markets, feed in tariffs) (F5) - Score 2
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8.1 Introduction

In the last two chapters, the findings were presented and analyzed from the two studies, the reporting of life cycle assessment (LCA) results, which help construct environmental sustainability transition pathways for the case study of the Saudi energy sector, and the reporting of interview results, which feed into materializing the Saudi NSI. These two sets of findings are combined in this chapter to produce a higher level of analysis and discussion that intertwine the qualitative findings with the quantitative findings in the light of the literature to present a possible *sustainable CM approach for the Saudi NSI*.

8.2 Towards a Sustainable Carbon Management ‘System of Innovation’

Chapter 3 showed how the oil and gas industry have placed Saudi Arabia in a leading role in the global oil market and have thus placed its economy amongst fast-growing developing countries, benefiting from ever-growing returns from rising oil exports. This trend is arguably going to change in the future, for many reasons owing to the challenges facing the world economy today and the dynamic changes shaping the future of the energy industries. The previous chapter has presented the findings in the form of the Saudi NSI as an account of its current developments as well as economic development over the past decades. This historical side enabled the identification of different agents across Saudi Arabia, that contributed to its economic development, and more importantly how their roles have shaped the development of a base for technology, science and innovation, or a lack of such an infrastructure thereof.

In this dissertation, it is argued that materializing an NSI underlies any innovation-spurring effort in a country or sector. Economic development in Saudi Arabia and therefore the *fabric* of its NSI has been characterized by its heavy dependence on oil. This has not only shaped the economy but also the society and policymaking. Constructing an NSI around the energy sector was

therefore important to identify the agents that support the Saudi Arabian economy, which will eventually form the backbone of any technological innovation system for the energy sector in Saudi Arabia, as summarized from chapter 4. It is because technological innovations do not occur in isolation but are rather a result of vigorous interactions and multi-dynamic events that are created from a network of agents that are embedded in the economy. This forms a base where transition could take place and sustainability pathways could be envisioned and then constructed and managed.

The NSI and sustainability transition pathways will enable the emergence of what is referred to here as a Saudi sustainable carbon management system of innovation (SSCMSI), this is the Saudi NSI with a special objective of managing CM technologies, policies and their application for spurring innovation in cleaner/cleaning energy technologies to eventually lead to a transition to a cleaner energy economy and towards a more sustainable future.

The figures (8-1 and 8-2) below show a schematic diagram of a proposed SSCMSI, and transition pathways, they summarize the frameworks used and applied to the Saudi context; these will guide the discussion in this section.

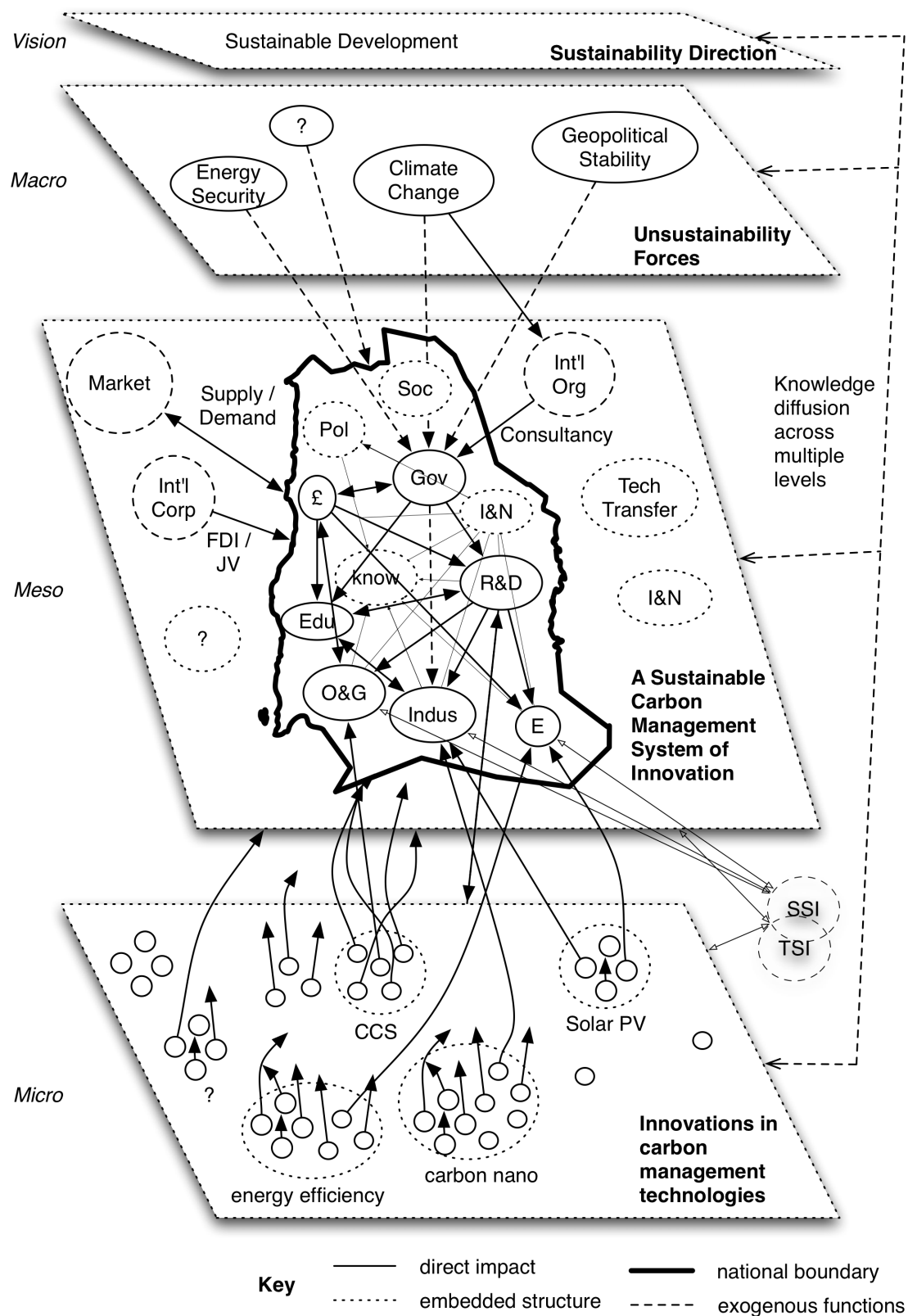


Figure 8-1 A schematic proposed framework for a sustainable carbon management system of innovation using MLP, transition theories and innovation system approach

Key

Abb.	Term
?	Uncertainty
£	Finance
CCS	Carbon capture and storage
E	Energy sector
Edu	Education sector
FDI	Foreign direct investment
Gov	Government
I&N	Institutes and networks
Indus	Industrial pillars
Int'l Corp	International corporations

Int'l org	International organisations
JV	Joint venture
Nano	Nanotechnology
O&G	Oil and gas sector
Pol	Policy
R&D	Research and development
Soc	Society
Solar PV	Solar photovoltaic
SSI	Sectoral system of innovation
Tech	Technology
TSI	Technological system of innovation

8.2.1 Contextualising Sustainability

Understanding the meaning of sustainability in Saudi Arabia requires the de-construction of multiple levels of analysis and an articulation of how forces within each level shape its transition towards a low-carbon economy.

Here, contextualising sustainability for the Saudi Arabian case will be explored by first de-constructing the levels using the MLP approach, transition management and borrowing concept from 'transition thinking' both of which were articulated in chapter 4; understanding the meaning of sustainability at each level and then identifying *unsustainability* forces and elements to construct sustainability pathways so as to overcome these unsustainabilities and manage the transition process effectively.

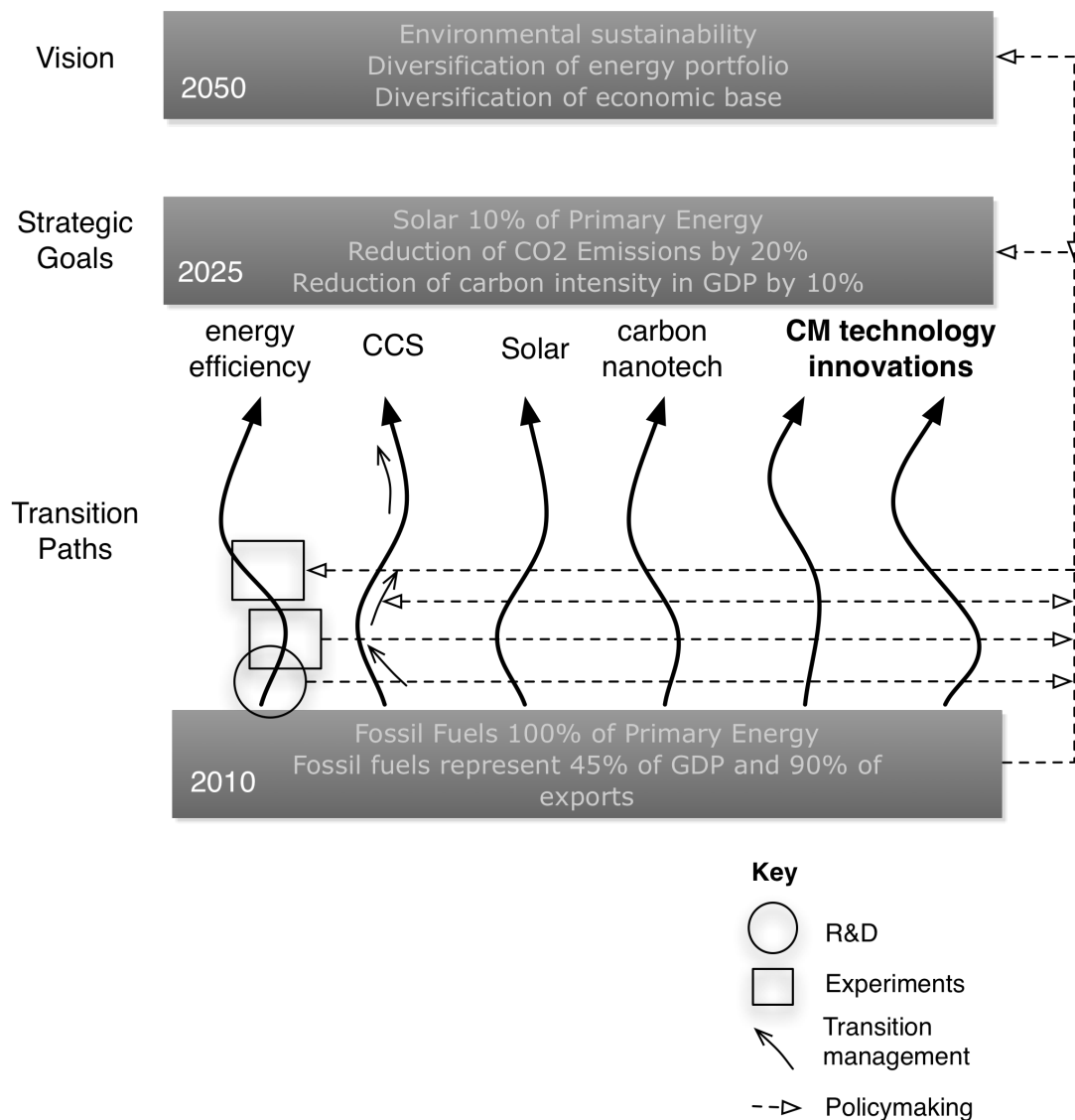


Figure 8-2 A Proposed Vision for a Saudi Sustainable Carbon Management System of Innovation, SSCMSI (Source: Author, based on Rotmans et al, 2001 and Kemp and Loorbach, 2006)

Figure 8-2 shows a schematic diagram for a vision for a SSCMSI and how a long-term vision can translate into strategic goals and transition paths for its energy sector. It starts with the current state of Saudi Arabia in 2010 using 100% fossil fuel for primary energy, and the current carbon lock-in of the economy where oil represent 45% of GDP and 90% of exports. Transition paths represent different cleaner energy technologies that could be pursued by the Kingdom, including energy efficiency, CCS, Solar PV, carbon nanotechnology and other CM technology innovations that shall become available (from chapter 5). The transition paths compromise of R&D efforts as well as experiments that are continuously managed to inform policymaking

(small arrows representing transition management) and are also shaped by policymaking (dashed arrows representing policymaking). The long-term vision for 2050 is for Saudi Arabia to be environmentally sustainable, with a diversified energy resources portfolio, and a diversified economic base. The short- to medium-term objectives for 2025 that will help achieve the overall vision include, exploiting solar energy and aim to meet energy demands by 10% through solar power, reduce the total national CO₂ emissions account by 20%, and reduce carbon intensity in the GDP by 10%. Below, the diagrams will guide the discussion:

1. Vision

Placed at the top level, sustainable development is regarded as the long-term vision that sets a sustainability direction for a Saudi transition; Sustainability is the pursuit of sustainable development to balance between the three dimensions: Saudi Arabia's oil-based economy, the environment and the society – creating [multiple] visions to enable transition management that will help use a *reflexive* mode of governance, guiding and steering towards these (Chapter 4).

A dimension to sustainability that emerged from the findings in the previous chapter is how Islam provides a holistic framework that holds sustainability meanings at its core. Arguably, pursuing [al-]*Siratt* or '[the] Straight Path' is a principle of Islamic thinking that correlates to a transition pathway – the idea that one should pursue a balanced pathway. Particularly, environmental sustainability is a sought-after objective for Muslims as discussed by interview participants. Therefore, as a Muslim⁵⁷ state that rules by the Quran and *Sharia* [Islamic] Law as its constitution and engage Islamic thinking in its society and government, it is an opportunity to enforce the element of environmental sustainability across the Saudi NSI, to instil a religious-based

⁵⁷ Saudi Arabia's creation as a 'partnership' between a religious leader (Abdulwahab) and a political leader (Ibn Saud) must a delicate religio-political balance. Therefore, the empowerment of the religious establishment is constantly present.

overarching objective in its society, government agencies, industrial pillars, research centres and academic institutions.

The religious establishment in Saudi Arabia plays a rather powerful role, even in policymaking. As discussed in Chapter 3, the religious establishment plays an integral role in state-building in Saudi Arabia, and especially in sectors that are deemed strategic, oil-policy has seen such interference. An example of the role of the religious establishment in influencing oil policy is the 1973 oil embargo to cut off oil supply from USA for their stance on the Palestinian-Israeli conflict, arguably, the Islamic ideology has driven this policy. The religious establishment also continues to play a role in shaping the education system, the society and general social policy in the country. The religious establishment which made vivid the Muslim identity and the responsibility to protect Muslim lands has equally fuelled such a decision. Therefore, the religious institution continues to shape policy at every aspect of governance. The energy policy in Saudi Arabia has been defined by dynamics in the international oil market as well as the global geopolitics, and in turn, has been shaped by international relations between consumers and producers of oil, namely, the Saudi-US relationship which is superior to other relationships. Previously, it has been done as a 'delicate balance' between supply and demand of oil from the American side, and other deals that are argued to support the relationship, mainly arms deal (see chapter 2).

However, it is not enough to have a mere vision, even if it is borrowed from Islamic tradition that is implemented in the society. A vision must be translated into transition paths, short-term to medium-term objectives and long-term 'contextualised' vision for Saudi Arabia.

Chapter 4 explained that sustainability could be contextualised by deconstructing the levels, scales and phases of innovation systems. Visions act as ideal states, similar to the state of 'utopia' – hence, unattainable but sets the direction. This vision may well translate into multiple visions corresponding to multi phases, multi timeframes and multi levels of analysis, and transition takes place as a result of co-evolutionary processes occurring

simultaneously across multi levels (MLP) by multi actors (NSI agents) and following [alternating] multi paces driven by actors and factors, whether inside or outside the boundaries of an NSI, which ultimately shape transition pathways:

(i) *Multi phase* refers to the state of the system and its corresponding vision, or the current state of the country and how its strategic direction is defined. In Saudi Arabia, the current energy base is locked in carbon being fuelled by fossil fuels and its economic base is locked in carbon being heavily dependent on oil-revenues, as also summarised in figure 8-2. These systems are also embedded within its society, institutions (rules, norms and regulations), market, industrial base, R&D intensity and direction as well as the way competence and competitiveness of the economy is defined and generated. The current phase of the Saudi NSI (chapter 7) is characterised by its dependence on a finite resource, a high-income [rent] from it, low R&D and innovation activity and a generally weak institutional structure with high bureaucracy, an incompetent national human capital with low college enrolment in science, technical and engineering fields, and therefore a weak industrial base, the tendency to buy and outsource technology- and knowledge-intensive products/services rather than develop it in-house, weak regulations and procedures for patent and IP with a weak culture for innovation, as well as institutional corruption. Some of these challenges are typical for developing countries, as discussed in chapter 4. This is the phase that transition processes start from, and a particular focus should be in tackling these ‘unsustainabilities’ that obstruct the activation of the Saudi NSI, in order to simultaneously lead transition paths towards sustainability.

In simple terms, the broadest definition of a sustainability vision is to pursue a future-state that is economically, environmentally and socially sustainable. In practical and more attainable terms, and to identify a phase-base definition of sustainability, the elements of sustainability must be integrated into an NSI to develop and assess sustainability indicators, and to consider a sustainability

direction that meets strategic directions for the country based primarily on the phase the current NSI is defined by.

Using sustainability thinking and considering the current state of the Saudi NSI, it may not be sustainable to move away from fossil fuels immediately, after all, the reserves of oil and gas are natural resources and are abundant, and part of environmental sustainability is to maximize these natural resources and utilise it efficiently and effectively. Also, economic sustainability suggests maximizing economic revenues for the country, these are today locked-in a fossil fuel system, and hence, it will be economically costly to move away from that system without managing a smooth transition and integration towards diversified sources of economic revenues. Moreover, social sustainability is always burdened by social inertia resisting changes to lifestyle, electricity options and embedded traditional institutions. Without a parallel shift in awareness, education system, and participation of the public, it may not be considered socially sustainable to expose the public to disruptions and/or sudden costly dramatic changes.

Saudi Arabia must 'maximize' its economic, environmental and social resources. Ideally, sustainability visions will take the shape of *shifting phases* through transition pathways: 1. An oil-based economy defined by maximizing oil resources and generating oil revenues to build a strong foundation for diversifying its economic/energy base in the [near] future; 2. A diversified economic base that focuses on building competences in non-oil sectors and an energy base that includes a mix between fossil fuels and other sources of energy and also forming alliances and networks to enable CM technological R&D; 3. Maximizing knowledge generation, technological innovation and competencies in strategic sectors to fit the [new] direction of the country by activating its NSI and their interlinkages within the system and with exogenous actors outside the system. Defining a vision therefore requires multiple visions for multi timeframes.

(ii) *Multi timeframes* refers to *evolving* visions that build on timeframes, short-, medium- and long-term. Although sustainability is a straightforward

and clear vision in the long-term, to meet this vision and translate it into workable multi attainable visions that are based on shorter timeframes, the definition and focus change. This means that sustainability objectives change over time.

A. Short-term sustainability aim: Exploiting carbon lock-in

In the short-term, owing to the fact that oil remains a strategic tradable and demandable commodity in global oil markets, constituting primary energy resources in the world, moreover, due to the fact that Saudi Arabia's NSI is locked-in oil and carbon, therefore, Saudi Arabia must exploit its oil resources to the fullest and maximize oil returns. This may seem unsustainable in the long-term but is in fact a necessity and an inevitable undertaking in the short-term that will contribute to its transition path towards sustainability.

It is a balance between economy, society and environment – transitioning away and abandoning a natural resource is not sustainable, especially one which provided and continues to provide energy to the world and is given partial credit to making possible the creation of a modern world economy and a modern civilisation. A short-term sustainability objective for Saudi Arabia, therefore, would be to employ 'cleaning' technologies with faster deployment that allow the continuous use of its existing system while at the same time do not add to the stock of CO₂ emissions; this is important for preparing for a shift towards sustainability.

Therefore, the short-term aim for Saudi Arabia becomes to employ cleaner (or cleaning) energy technologies that are characterised by fast deployment, namely CCS technologies from the portfolio developed in chapter 5. While at the same time investing in R&D projects and communicate medium-term and long-term objectives across the NSI to form the building blocks for technological innovations to be generated as a result of interactions and investments in the NSI.

B. Medium-term sustainability objective: Bridging a smooth transition

Over the medium-term, building on from short-term aims, this should set the scene for medium-term sustainability objectives that will enable it to move towards long-term sustainability visions. Thus, the role of these objectives is to create a smooth transition by including advancing technological [and innovative] competence through a portfolio of CM as well as enabling actors across the NSI.

Hence, one could argue that a knowledge-based economy emerges as a *sustainability* aim to satisfy technological innovation needs. Adopting a portfolio of CM technologies would serve such a short-term aim, compiled in chapter 5, these are vital for Saudi Arabia to maintain a smooth transition towards environmental sustainability without disrupting economic and social sustainabilities. CCS technologies, which were applied to the case study in the Saudi electricity sector (chapter 6), Although it may seem unsustainable to aim for expanding the use of fossil fuels, such a portfolio is important for the overall sustainability objective to be achieved.

Mineral carbonation is another technology that was discussed as part of the portfolio for Saudi Arabia and provides immediate opportunity for Saudi Arabia to become a leader in carbon management. Assessing technologies and increasing R&D intensity in Saudi Arabia to come up with a portfolio similar to the one compiled in chapter 5 in this dissertation should be a dynamic on-going process that fuels Saudi's NSI.

C. Long-term sustainability vision: Sustainable development

Sustainable development is the long-term vision that should be pursued, this acts as the 'focusing device' on which strategy and plans are directed towards. A vision provides a picture of an 'ideal' situation that generally sets the direction for short- and medium-term objectives and aims. Therefore, sustainability vision translates differently to countries in the short-term but meet closer in the medium-term towards one direction in the long-term.

A long-term sustainability vision for Saudi Arabia is to create an economy that balances between its environment and society as well as pursue sustainable economic development. Saudi Arabia's long-term sustainability must enable it to pursue technological innovations and utilise more sustainable energy resources, this includes to further advance and strengthen its economy, fully exploit solar energy, as well as develop a competent human capital that will be able to generate technological innovations to overcome unsustainability challenges.

Sustainability sub-visions or *objectives* for Saudi Arabia could be to: (i) maintain the marketability of oil in global oil market, (ii) diversify oil-based economy to include sources of income that do not depend on an exhaustible natural resource, (iii) utilise oil money to create the necessary *functions* to 'activate' the NSI, (iv) advance a knowledge-based economy that is able to stimulate technological innovations in CM.

(iii) Multiple Levels

1. Landscape at the Macro level: Defining unsustainabilities

At the macro level, the bigger picture of the world is presented where the [socio-technical] landscape identifies *unsustainability* forces that shape the development (or transition) process, hence the arrows in figure 8-1. Forces that emerge at the international arena and require international attention exert pressure on Saudi Arabia in direct and indirect ways, these include: (i) *Climate change* as a force represented in bold arrow to show the focus of this dissertation, it is forecasted to impact Saudi Arabia's ecology, climate, biodiversity, human health and livelihood (chapter 2), thus, it provides a direct impact represented by a straight-arrow to the Kingdom. Climate change also impacts energy security (dashed line) as a result of [Saudi oil importing] countries' efforts to diversify their energy mix in the future and therefore providing (ii) *energy security* issues and in particular 'demand security' for Saudi Arabia as efforts intensify for a shift away from fossil fuels; (iii) *oil prices* fluctuations remain to be a force that affects the Kingdom directly as it

determines oil revenues, it also affects the Kingdom indirectly by affecting oil-importing countries that change demand patterns according to prices and whom also could consider alternative options, even if in the short-term, and thus a direct line is shown to the market and to the financial body in Saudi Arabia and finally (iv) *geopolitical stability* which directly impacts global oil markets and also indirectly affects Saudi Arabia. Recent events in the Middle East, the Arab Spring⁵⁸, caused disruptions in the global oil market and being the swing producer and one with largest oil capacity, Saudi Arabia increase its production to fill in gaps in oil supply created by countries hit by geopolitical instability such as the case in Libya since February 2011, these geopolitical factors affect the dynamics of global oil market. (v) The question mark represents an unsustainability force that will emerge in the future and that will have an impact on countries, and Saudi Arabia.

Therefore, the landscape for Saudi Arabia entails addressing these unsustainabilities by creating transition paths that will enable: 1. Exploiting sustainable energy, which means pursuing a transition towards a cleaner and sustainable energy and towards breaking away from fossil fuels in the energy sector, therefore, reducing CO₂ emissions and making more oil reserves available for exports to global oil markets, this will also enable the use of cleaner and more sustainable energy resources for future generations; 2. Diversification of its oil-based economic-base, this will shift the dependency on 'rents' from an exhaustible natural resource to a diversified portfolio of revenues that are generated sustainably such as building competitiveness and competence in strategic sectors; 3. Developing a dynamic system of innovation and activate it to stimulate technology innovations in the energy sector and in CM technologies to maintain Saudi Arabia's position in the global energy market by leading CM technologies.

Taking this grand and seemingly straight-forward vision to lower levels of analysis, e.g. at a country-level or regime level, would add new dimensions and also add complexity as will be discussed.

2. Patchwork of Regimes at the Meso: NSI as a framework for sustainability

The meso level encompasses '[patchwork of] regimes' which relates to different [strategic] sectors within a national economy. 'System of Innovation' emerges as a sustainability framework characterised by enabling a foundation that supports spurring innovation for a shift towards a more sustainable future.

Figure 8-1 shows the meso level showing the national border of Saudi Arabia with bold black, and the actors and factors affecting it placed outside the national border. The diagram also shows agents across its NSI, as per the discussion in the previous chapter. Main actors in the Saudi NSI: the government (Gov), research centres (R&D), Industrial pillars (Indus), the oil and gas industry (O&G), the energy sector (E), the education system (Edu) and the financial system (£). These are shown as the building blocks that support a sustainable carbon management system of innovation. Arrows between these actors, as well as from/to outside national borders represent interactions and direct impact. Dotted-circles represent embedded structures such as knowledge (know), institutions and networks (I&N), society (Soc) norms, policies (Pol) as embedded within Saudi Arabia, and other embedded structures outside the Kingdom includes technology (Tech) transfer I&N and other embedded structures that become available in the future. Exogenous functions are also represented by dashed circles, these include the export and import market as well as the local market dynamics that define the supply and demand pull and push, international corporations (Int'l Corp) which represents actors that introduce foreign direct investment (FDI) and joint ventures (JV) that contribute in generating knowledge and enriching the NSI, and international organizations (Int'l Org) as well as international consultancy firms that play a significant role in enabling development projects and serve as inputs to the NSI.

The networks and interactions are enabled by embedded structures at the meso level, such as technology transfer as well as existing institutions and networks, embedded structure is also represented by a question mark to indicate futuristic or unidentified constituent that shape the 'technological absorptive' process and affect the innovative capacity. Dynamics within this level inform the SSCMSI.

Sustainable development as a framework to raise environmental policy standards has been first mentioned in the last two Saudi five-year plans (2005-2015). However, the challenge laying ahead for Saudi Arabia includes communicating this vision across institutions, organizations and political will to implement sustainability in all works of the country.

In order to activate Saudi's NSI, the challenges that it currently faces, which emerged from the findings (chapter 7), form obstacles that must be tackled:

- *Bureaucracy*

The challenge of bureaucracy could be solved in the short-term by continuing to create ad-hoc committees and royal decrees that overcome bureaucracy. This has been done in the history of Saudi economic development, especially for managing mega projects. However, this 'quick fixes' direction is not sustainable. Sustainable [reflexive] governance should enable the creation of institutions, the decentralisation of authority, and the reform of laws and regulations that impede the innovation process. To accelerate the innovation process and create an infrastructure that activate Saudi NSI and support a dynamic process that updates short-term policy by pursuing sustainability in the long-term.

- *Vision*

The government in its capacity as the highest authority must adopt an overarching vision of sustainability that will be communicated across agents in the economy. The government initiative 'Vision 2020,' which was described in the previous chapter, is a step in the right direction; However, the concern is in its enforcement across the agents, the readiness of the agents, their 'innovative capacity' must be assessed continuously and factors that influence

innovation must be dealt with simultaneously, for example, other challenges that Saudi NSI faces, that are discussed here. Using figure 5-2 which provides a proposed vision, such a vision for Saudi Arabia will help (1) identify areas that will be possible means and platforms for pursuing that vision, (2) guide problem-solving step-by-step by targeting short-term and medium-term objectives, (3) measure the performance against a set of sustainability benchmarks, (4) identify actors and networks within the economy that must participate in pursuing visions, (5) prioritise available resources of time, money, human capital and other resources to meet objectives and visions.

- *Environmental sustainability*

Environmental sustainability must be incorporated in the overall vision, creating targets for carbon reduction like the one proposed in figure 8-2. This will encourage businesses and homes to incorporate energy efficiency measures as well as carbon footprint consciousness by individuals, business, and government agencies to aim to reduce the overall national CO₂ account. Environmental government institutions represented today by MEPA and perhaps the statistical department at MEP will have the responsibility to provide statistics of the national account of CO₂ and individual companies to assess and measure performance in reaching the reduction objectives of their individual CO₂ footprints.

- *Industrial base*

Developing the industrial base for Saudi Arabia is connected to many other challenges that are often common in developing countries, such as strengthening the overall economy, the reform of the education system, raising the enrolment and graduates in the science, technical and engineering field, and thus raising the national labour technical level, developing in-house skills, capabilities and technology-intensive products and services rather than buying them or outsourcing them abroad, especially in critical sectors such as energy, and finally, making policies that will help in the expansion of the industrial base. These policies could be seen in the new direction that the Kingdom is taking towards sustainability, more specifically, by creating new economic cities (KAEC and others) and creating a technical university

(KAUST) with a science park and incubators, and with Clusters initiative, these steps are in the right direction. However, the concern is for these initiatives to remain isolated and scattered in islands-like efforts. The NSI aims to integrate initiatives to encourage participation from different actors and agents across the economy, the challenge is to include policies that will promote such interconnections between actors and within them.

- *Institutional structure*

The tendency to resort to short-term quick fixes, such as royal decrees and ad-hoc committees could be indicative of flaws in the governance and institutional structure in the Kingdom. An effort should be made to reform institutions relevant to innovation, such as laws, regulations, and policymaking that will affect the innovation process and establish organizations (innovative actors) and formal procedures (innovative factors) in a way that will formalise communications between ministries, industrial pillars, research institutions to support a greater innovativeness capacity and ultimately spur technological innovations.

- *In-house versus outsourcing*

Saudi Arabia must work towards developing its own technologies, and aim for encouraging technology and knowledge transfer that will enable its national labour and local organizations to invest in developing the technology/service.

- *Education system*

The education system is an influential contributor to economic development and a key in advancing Saudi NSI because it is one of the main agents that make up the building blocks of NSI, it is responsible for creating a national labour that will support the innovation process. As discussed in the previous chapters, the MOHE has launched programmes to upgrade the education system in the Kingdom and the scholarship programme that continues to provide Saudi citizens with education abroad in thousands. Education system indicators such as literacy, primary education, secondary enrolment and tertiary enrolment, as well as ensuring good science, technical and engineering fields and raising enrolment and graduates. The education system determines the fabric of the social capital, which in turn determines

the culture of innovation, and creativity that constitute a NSI (more will be discussed below under social capital).

3. Niches Novelty at the Micro Level: LCA as a sustainability tool

At the micro level, niches [novelty] of technological innovations are born, these include technological innovation for cleaner energy that were developed in chapter 5 are represented in the schematic diagram 8-1 in groupings, and represented in transition pathways in diagram 8-2.

Sustainability at this level is about sustaining the stimulation of innovation in CM technologies. This is done by creating a supply-push from technological innovation, R&D and applied research at the micro level, and utilising a demand-pull at the meso level which create gaps and 'windows of opportunity'; technological innovations then come to fill these by creating new configurations brought by new technological innovations that will adjust the current socio-technical regime.

The micro level of analysis embraces technological innovations that develop in the energy sector and which often transcends national borders. It carries criteria from TSI and SSI which represent an accumulation of technological learning and embody an account of knowledge at a global scale, (represented by the grey line and dashed circle for TSI and SSI in diagram 8-1). Therefore, although the micro level represents a focus on technological innovation it also transcends into global level via the SSI/TSI link. As has been discussed, the focus becomes on building a system of innovation around CM technologies which will help further stimulating the transition.

The diagram 8-1 shows competing technological trajectories originated at the micro level and as technical advances triumph, technologies emerge from the bottom to the top making opportunities for economic success to finally diffuse across the economy into the meso level. The portfolio of CM technologies (chapter 5) which included: CCS, Solar, carbon-based materials and nanomaterials, and mineral carbonation as well as carbon industrial uses are

all emerging CM technologies that promise to help combat climate change by reducing the national account of CO₂.

For Saudi Arabia, a diversified portfolio of CM technologies that fits the strategic priorities and sustainability direction must be coupled with sustainability tools such as life cycle assessment (LCA) that will provide feedback on experiments and assist in decision-making. Both tools, portfolio creation and conducting experiments, are regarded as tools for sustainability to assess different niches and therefore regulate, manage and stimulate prospective technologies that are likely to facilitate the transition, this could assist reflexive governance, which will enable managing a transition.

In chapter 6, and schematically represented in figure 8-2, an in-depth case study for the Saudi electricity sector has been provided; presenting transition pathways reflected in different scenarios for cleaner energy for Saudi Arabia in the form of predictions of energy use and CO₂ emissions up to year 2025 by applying both CCS and Solar PV to the energy sector. Using LCA studies conducted on CCS and Solar PV, such systematic assessment of prospective technologies is required to assess their prospects for the future of Saudi Arabia.

This portfolio of CM technologies developed for Saudi Arabia may not present the ultimate technological break-out from the fossil fuel 'lock-in' problem but will give insights into how Saudi Arabia could use its portfolio to attain sustainability objectives in the short-term, i.e. how it could maximize the returns from its oil reserves while also identifying ways to get rid of the CO₂ problem. Technologies at the research phase could be incubated in science parks and research labs, these are being developed across the Saudi NSI as discussed in the previous chapter. This marks the start of breaking from its carbon lock-in while building a robust economy, and move smoothly from economic development generated through a generous oil-income gained almost effortlessly, to that which is generated through a knowledge-based economy built on stronger institutional structure, better education system and

a stimulation of intense R&D activities across the economy – managed by a reflexive mode of governance.

However, the portfolio of CM technologies, particularly CCS and carbon-based technologies may ‘reinforce’ carbon lock-in and could therefore slow down rather than ‘accelerates’ a transition towards sustainability.

It was explained in chapter 5 that the portfolio of CM technologies put together has been selected based on sustainability objectives and especially short- to medium-term. This is now explained here as due to the fact that most CM technologies although environmentally sustainable carry some unsustainability measures which by itself may not seem sustainable but without which a sustainability path would not be attainable.

Although CCS reduces CO₂ emissions, almost immediately, and requires no radical changes to the infrastructure for the existing oil-based energy system, it does use additional energy and therefore produces more CO₂ that eventually becomes sequestered, as explained in chapter 6. Thus, in sustainability terms, CCS may not be considered environmentally sustainable, especially in the long-term, because it accelerates the use of energy, in this case Saudi Arabia’s natural resource of oil reserves. Yet, it also provides a ‘transitioning’ solution or a ‘bridging’ technology, especially if some of its components is mature technologies, also, primarily due to the fact that Saudi Arabia has built competence gained in the oil and gas industry and could be utilised in adopting common components of CCS, such as the pipeline system, EOR, and industrial separation of CO₂, all of which are mature technologies. Whereas other CM technologies (including some CCS components) are in the research phase, demonstration or mature market that requires radical changes to the system. Also, considering the ‘phase’ of an oil-based economy, which should maximize oil income.

On the other hand, other CM technologies in the portfolio of CM technologies would be adopted at various timeframes, many which take longer to develop technological competence and innovation in, such as renewables and mineral

carbonation. Competence building and improving the innovative capacity is a gradual process that must be invested in and developed over the medium term. The generation and diffusion as well as utilization of the technology is faster, easier and less expensive than renewable energy systems.

Therefore, the premise that carbon lock-in is a challenge in the face of implementing cleaner energy technologies could be rejected if the cleaner energy technology that is to be implemented is CCS. In fact, the carbon lock-in situation could be argued to facilitate the adoption of CCS as it presents a way to bridge the currently fossil fuel based world to a future of energy that is more sustainable. This future is yet to be comprehended, for, it is difficult to imagine a world that fully runs on renewable energy, a system of technology that relies mostly on biomass, and renewables making only 0.4% (0.1% solar) as previously explained. Therefore, if the contribution of solar energy is negligible, it cannot fuel energy demands of the entire economy, but rather, it could be amongst other energy sources in a diversified portfolio of energy technologies.

8.2.2 Managing the Saudi Sustainable Carbon Management System of Innovation

The SSCMS is a complex and expanding system, as the knowledge for CM expands, so does the system. It undergoes a continuous transition towards a more sustainable vision, using a progressively growing knowledge accumulation in the system and the reflexive governance to generate innovation policy. Innovation policy is by itself dynamic, i.e. it is not a stagnant function but rather continuously seeking new technologies, directions and *fulfilment* of the socio-technical needs by the country to pursue sustainability.

As discussed in chapter 4, managing a transition includes eight steps and to incorporate these steps into the context of Saudi Arabia, created a 'blue print' for managing such sustainability transition pathways:

A sustainability vision proposed for the long-term (2050) vision for Saudi Arabia includes: environmental sustainability; diversification of the energy

portfolio; and diversification of the economic base. The vision translates into strategic objectives will generate short-term policy utilising forecasting and back-casting for the energy sector in Saudi Arabia. Involving policymakers and businesses to reach it within a specific timescale. A vision that will help guide thinking and inform processes which will require the participation of different agents in the economy to achieve defined outcomes i.e. materialised outcomes/output, as well as learning objectives, this will be achieved by creating visions, new paths for development.

Strategic Goals: a proposed short- to medium-term (2025) strategic goals for Saudi Arabia includes: meeting primary energy by 10% through solar power, reducing CO₂ emissions by 20%, reducing carbon intensity in GDP by 10%.

Current State: fossil fuel fuelling 100% of primary energy, representing 45% of GDP and 90% of exports. The current state dictates where transition paths start.

A portfolio of carbon management technologies for the country must be put together (chapter 5) and use sustainability tool to assess possible transition pathways of these technologies (chapter 6), life cycle assessment (LCA) is used as a framework (explained in the following section 8.3). Saudi Arabia has witnessed a wave of privatisation particularly around 2005. This suggests that such private firms could hold the potential to *innovate* because the driving force for innovation at this level is money. This accelerates the *diffusion* process from the science park to the greater economy. Therefore their learning process and capabilities emerge as important factors for the Saudi NSI and ISs within.

8.3 Functions of The Carbon Management ‘System of Innovation’

From chapter 4, it is understood that system [of innovation] growth can be determined by the *fulfilment* of functions and how these functions *interact*. As a way to ‘operationalize’ and assess the growth of the innovation system, here, the SSCMSI will be discussed based on the portfolio of CM technologies developed in chapter 5.

Technology innovation lies at the heart of economic development and Saudi Arabia has been a 'rentier' state that depends on its natural resources' rent to generate its revenue, and buying technology-intensive products and services and outsourcing projects. Technology innovation must be spurred and developed in-house; The NSI approach and TSI functions provide tools to evaluate the *structural* and *functional* competence of the Saudi economy, and a focusing device to assess the energy sector more closely.

Here, a total grade is given to each function based on findings from this dissertation, [1 is poor, 2 ok, 3 average, 4 good, 5 very good].

8.3.1 Entrepreneurial Activities (F1)

As the first function in a system of innovation, the status of entrepreneurship in Saudi Arabia lies at the core of its innovation system and determines the effectiveness of its NSI and also for diffusing technological innovation in carbon management. Entrepreneurs act as the link between technological innovations and the market, they take the risk to turn these ideas, after experimentation and development, into business opportunities.

The role of entrepreneurship in Saudi Arabia is taking shape and efforts to encourage the development of small- and medium-sized enterprises (SMEs) are also spreading. There are four main organizations that track, manage and stimulate entrepreneurship in Saudi Arabia: 1. Saudi Chambers of Commerce and Industry, operating under the Ministry of Commerce and Industry, different chambers of commerce across Saudi Arabia provide a platform between the public and the government and provide administrative services to start businesses; 2. Saudi Entrepreneurship Development Institute; 3. National US-Arab Chamber of Commerce; 4. Global Competitiveness Forum and 5. SAGIA.

Moreover, a number of initiatives have been created, dedicated for encouraging youth to participate in entrepreneurship, these are:

- The Centennial Fund (TCF 2011) created during the celebration of 100th anniversary of the creation of Modern Saudi Arabia, TCF attracts young Saudis who are keen to develop their business ideas.
- Prince Salman bin Abdulaziz Young Entrepreneur Awards, a SR 100,000 (£16,600) cash prize award for Saudi nationals between ages 18-40 who have established a business or developed a project that has “significant contribution to society in one of these six categories: industry, service, trade, technical, agricultural and leadership” (SalmanAward.com 2011),
- KAUST has established a Seed Fund that starts with \$50,000 (£30,000) pre proof-of-concept funding and may invest up to \$250,000 (£154,000), a fund which aims for "investing into technological innovations that lead to the establishment of enterprises.” (KAUST 2011)
- Bader initiative under KACST to incubate some of the initial start-up companies and funds them for the first years until they grow.
- Saudi Fast Growth Awards is an annual ranking of fastest-growing companies in Saudi Arabia, (SFG 2011). Founded in 2008 as a SAGIA Private Sector Initiative Programme, the National Competitiveness Centre, jointly with other local companies, SFG aims to recognize and award the fastest growing small and medium-sized enterprises (SMEs) in the Kingdom. According to their latest list of SMEs, the industries for companies 5-years and more in establishment recorded are presented in the table below.
- Bab Rizq Jameel (see chapter 7), part of its work on raising employment is enabling entrepreneurs through various programmes. These, however, are targeted at the weak-educated or uneducated.

As discussed in the previous chapter, entrepreneurship efforts in Saudi Arabia are also supported through the WTO membership, the SIDF under MF, and Saudi growth under SAGIA, the latter has also triumphed in rising ‘ease of doing business’ ranking to 11 (Chapter 7). Figure 8-3 shows entrepreneurship activities in the Saudi Growth award (2011), showing the different sectors that entrepreneurs choose. The market in Saudi Arabia, as discussed in the previous chapter, does not have industries that are based on technological

innovation, the top 100 companies shown in the previous chapter show that most companies are concentrated on the industrial sector, banking sector, contracting, trade and others. The education system, also discussed in the previous chapter, show students opt for education and humanities field of study (60%), social sciences (20%), whereas scientific, technical and engineering field of study remains minimal. Therefore, entrepreneurial activities in the diagram under 'hi-tech and telecommunication' is not in technology-innovation field but rather it is selling imported products, these are not based on in-house product developments.

Therefore, it is important to provide an environment that encourages the creation of more SMEs in order to further drive innovation and entrepreneurship. Policies are needed to define a unified operational structure that shall raise a skilled human capital, improve funding opportunity, provide information, create policy structure, regulations and incentives, and improve the relationship between SMEs and large enterprises. Moreover, for a transition from a stagnant entrepreneurship in the sectors of carbon management technologies, there is a need for a government authority that handles SMEs regulations and steer entrepreneurship efforts towards a defined structure where it could introduce the country's strategic interests and direction towards [environmental] sustainability and provide policies that supports carbon management technologies with actor-networks connected to existing networks, R&D centres, the industry and business community. Including youth programmes for awards and an incentive system particularly in CM.

Saudi SMEs & Start-ups in 2010 by sector

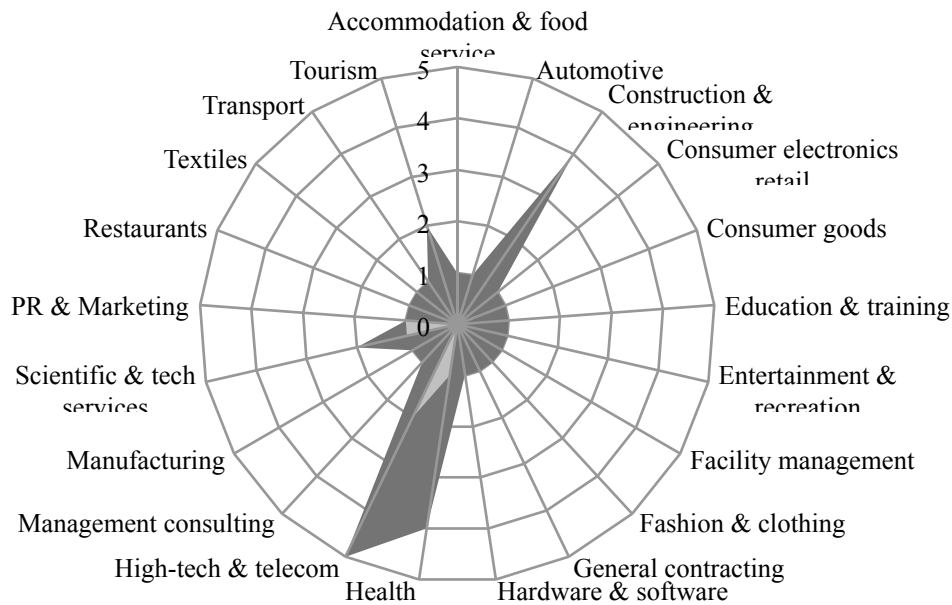


Figure 8-3 Saudi SMEs and Start-ups in 2010 by sector (Data source: Saudi Growth 2011)

Figure 8-3 shows Saudi SMEs and Start-ups in 2010, according to Saudi Growth (2011); the blue area shows a number of the SMEs in each sector total of which is 22, and the red area shows the number of start-ups, total of which is 8. The top sector is 'high-tech & telecom' followed by 'construction & engineering' then 'scientific & tech services' and tourism, the remaining sectors are equal.

8.3.2 Knowledge Creation/Development (F2)

Knowledge creation or development includes technology R&D activity or intensity as a performance measurement for [technology] innovations. R&D intensity in Saudi Arabia can be measured by the output of its NSI agents, and those more pertinent to energy; this is lead by KACST the government lab. R&D centres in the Kingdom were discussed in the previous chapter, these include Aramco, SABIC, water desalination, health sector, SECO, and large business firms that generate capital and contribute to the Kingdom's economy.

To measure the intensity of R&D, the number of patents registration by organizations could be considered (Chapter 7). There are 109 total Saudi patents registered between 2005-2009, Saudi Aramco contributed a total of 55 registered patents, SABIC (17), KFUPM research institute (12), and the remaining are contributions from other organizations and individually-owned patents. Knowledge development in CM technologies will be stimulated by directing R&D and research grants in relevant organizations, Saudi Aramco is employing this direction gradually (Chapter 7), SABIC and KFUPM also are taking up research in CM technologies, namely, how can the petrochemical industry in Saudi Arabia participate in carbon-based applications (Chapter 5).

Moreover, knowledge creation/development can be achieved through the funding of projects and research in CM technologies. In the previous chapter, one of the participants (P9) explained that Saudi Arabia through its state-owned oil company activities in carbon management, Saudi Aramco has participated in developing CCS technologies by direct funding of the Weyburn-Midale CO₂ project, the world's first CO₂ measuring, monitoring and verification initiative. However, through such a funding, Saudi Arabia does not activate F1 but rather F2 via 'outsourcing' R&D. This may suggest that technological innovations in CM are not being developed in-house, yet this could be considered as a first step towards the activation of NSI, and CMTSI. Establishing [exogenous] networks will help strengthen NSI actors, which will in turn activate knowledge diffusion and technology transfer. To have a pilot project in the Kingdom (CCS in Ghawar field, Chapter 7) using established alliances will help build knowledge in CCS technologies and expand R&D, project experiments, demonstration and deployment.

In addition, the state-owned oil company, Saudi Aramco, is showing interest in exploiting CM technologies and plans to create its first pilot project in 2012, particularly focusing on R&D in CO₂-EOR, even more recently, it has declared plans to delve into solar energy R&D.

Moreover, renewable energy research although has started since the 1970s, as discussed previously, it has been revived today with debates on energy

and climate change gaining momentum, particularly with new initiatives, such as the establishment of KAUST, and future KACARE and KAPSARC. The national research lab at KACST is also strengthening its RE research; the establishment of four centres of excellence, in renewable energy, physics, nanotechnology, under three universities will potentially increase R&D intensity in CM technologies.

More sponsoring of R&D by the Kingdom is seen in a variety of solar energy experiments including a desalination plant in Jeddah, fed off corrosion in underground pipelines, heat a school in Tabuk and electricity to a village in north of Riyadh.

Research in carbon-based application in Saudi Arabia is still at the research phase, efforts are being made particularly at the chemical engineering department at King Saud University and SABIC Polymer Research Centre – working together to examine the application of nanocarbon polymer composites.

KACST has produced individual reports on the status of R&D in strategic sectors, to measure its R&D intensity, the following table provides an account of publications:

Table 8-1 Knowledge Creation in Saudi Arabia in selected sectors between 2002-06 (Source: KACST 2011)

Field	Number of Publications	Field share of KSA Publications	Field share of Global Publications	Activity Index
Medicine	8300	40.10%	29.40%	1.36
Engineering	3402	16.43%	15.44%	1.06
Chemistry	1746	8.43%	7.21%	1.17
Biochemistry, Genetics and Molecular Biology	1648	7.96%	12.12%	0.66
Physics and Astronomy	1390	6.71%	10.62%	0.63
Mathematics	1193	5.76%	3.35%	1.72
Materials Science	1171	5.66%	7.05%	0.80
Chemical Engineering	1163	5.62%	4.22%	1.33
Pharmacology, Toxicology and Pharmaceutics	1148	5.55%	3.80%	1.46
Agricultural and Biological Sciences	1105	5.34%	6.74%	0.79
Energy	1050	5.07%	1.79%	2.84
Computer Science	894	4.32%	4.17%	1.04
Environmental Science	872	4.21%	3.94%	1.07
Earth and Planetary Sciences	778	3.76%	4.37%	0.86
Immunology and Microbiology	571	2.76%	3.57%	0.77
Neuroscience	423	2.04%	2.99%	0.68

Source: SRI International Analysis of Scopus and SCImago data.

Table 8-2 Saudi Arabia's patent by field (Source: KACST 2011)

USPTO Class	Name	Patents
169	Fire Extinguishers	16
502	Catalyst	12
520	Synthetic Resins	10
62	Refrigeration	6
73	Measuring and Testing	6
114	Ships	5
702	Data Processing	5
428	Stock Material or Miscellaneous Articles	4
405	Hydraulic and Earth Engineering	4
422	Chemical Apparatus and Process Disinfecting, Deodorizing, Preserving, or Sterilizing	4

Source: Delphion

Note: This table shows only classes with 4 or more patents between 1996 and 2006.

7.6.1 Knowledge diffusion (F3)

This is a reflection of the interconnectedness between actor-network in the NSI for national collaboration on knowledge diffusion activities, such as conferences, research projects, strategic plans, policies and targets.

Knowledge diffusion efforts in Saudi Arabia for carbon management technologies and environmental collaborations include [but not limited to]: the first CM Symposium in 2005 Saudi Arabia provided a platform for knowledge diffusion, projects opportunities and bringing together related-skills and calibre in the Kingdom; the CDM Conference in 2006; the [3rd] CSLF which was hosted in Al-Khobar on 28 January 2008; Workshop on Solar Energy in Al Khobar in February and July 2010 hosted by KAPSARC; Workshop on CCS Project in Dhahran in June and October 2010 sponsored by KAPSARC; Workshop on Energy Efficiency in Dhahran on June 29-30, 2010 organized by KAPSARC. These provide a platform for diffusing knowledge to help materialise the TSI for carbon management technologies – it provides the building blocks of national collaboration between its actors, nationally and internationally.

This function (F3) suggests that R&D is communicated outside its own settings, in the institutional structure of agents that deal with energy and the environment in Saudi Arabia, this is active particularly between Aramco and SABIC, the two indigenous firms in the economy, and KFUPM, the education institution. Other R&D interlinkages across other sectors are still weak but taking shape in recently announced initiatives discussed in the previous chapter, namely, KAUST, KAPSARC, and K.A.CARE. These initiatives are being established with collaboration of existing actor-networks such as companies (Aramco), international consultancy firms (SRI, PE amongst others), research centres (KACST), and universities (KAU, KSU, KFUPM). This is done by appointing senior members to act as part of an interim team, which participates in founding the organizations and eventually return to their home institutions, these however remain very early stages of TSI. In addition, NEEP is an initiative which communicates its vision with actor-networks within the Saudi economy and energy sectors could be part of this function in the CM TSI. In terms of CM technologies knowledge diffusion, this primarily depends on developing the NSI around CM technologies and strengthening the network and interconnectedness between different actors.

8.3.3 Guidance of the search (F4)

Guidance of the search (expectations, visions, policy goals, customer demands, selection) is a direction that is undertaken by a country, discussed earlier on '*contextualising sustainability*', which constitutes that heuristic guidance for Saudi Arabia. The Kingdom's official stance on international treaties, frameworks and conventions could provide an overview of the status and effectiveness of this function (discussed in chapter 2 and 3).

The guidance function includes defining a unifying objective and/or overarching policy targets to present expectations so that resources would be mobilized towards developing technological innovation in CM technologies. Figure 8-2 shows how such a vision is defined into strategic goals that set the direction of transition paths. Sustainability and moving towards a cleaner energy economy must start at the top, this political will creates a direction for organizations. In Saudi Arabia, this 'guidance' framework is starting to emerge, especially with the undergoing establishment of KACARE, KAUST, and KAPSARC. However, this direction should support the development of technological innovation and not only outsourcing of technologies so as to create a bottom-up push from R&D centres, and not only a top-down direction, policies and grants.

In chapter 2, an overview on Saudi Arabia's stance on international environmental treaties on climate change has been provided. These include the Kyoto Protocol and the Bali Roadmap – although both are embraced by Saudi Arabia, however, as discussed earlier, international climate change regulations are not progressing as expected, they have not proven to be an effective tool, especially because of lack of enforcement. However, Islamic ideology which is endorsed by the Kingdom, and encourages environmental sustainability and invites a transition towards sustainability, could be utilised in policymaking.

The recent history of climate change activities in Saudi Arabia starts with its ratification of the Kyoto Protocol in May 2005, and then its joining of the CSLF in September of that year. In May 2006, the Kingdom held the first regional

CM symposium, and in September of that year it held a regional CDM conference. In November 2007 it pledged \$300 [£183] million for R&D in energy and the environment. Saudi Arabia was instrumental in reaching the Bali Roadmap, in December of 2007. In January 2008, Saudi Arabia hosted the 3rd CSLF conference. Following that, through 2009 it has actively participated in UNFCCC – COPs in Poznan and Copenhagen. In January 2010, CDM conference was hosted in Saudi Arabia.

In the previous chapter, participants discussed the stance of Saudi Arabia on climate change negotiations and arguments were summarized to show that although the Kingdom is keen on participating, it is also pushing for a ‘fair game’. For instance, some participants and researchers believe that oil-producing countries are particularly targeted in climate change negotiations, Norway’s deputy oil minister have stated that the exclusion of CCS from CDM is “*seemingly subjective and politicized reasons rather than those drawn from any objective analysis*”.

The Kingdom is concerned about its oil-based economic development in a carbon-constrained future and therefore has taken a defensive stance, discussed in chapter 2, this was also reiterated in the previous chapter by some participants. Therefore, although knowledge diffusion of CM technologies are pursued with the guidance of these environmental standards, treaties and negotiations, Saudi Arabia maintains a delicate balance between the two directions. It has, however, reassured its commitment to cooperate with international organizations. For example, CDM DNA is an initiative in collaboration with the UN (DNA-CDM 2011)

Statements on behalf of the Kingdom have been communicated in international environmental negotiations (Tayeb 2007). UNDP in Saudi Arabia provides a guidance for research in a number of areas, through eight goals that cover eradicating poverty, primary education, gender equality and women empowerment, reducing child mortality, maternal health, HIV/AIDS, amongst which is ensuring environmental sustainability and development projects collaboration (UNDP 2009). For example, LCA for CM technologies provides

an experimental-based framework that provides feedback on technologies from an environmental costs perspective. This will provide insights to policymaking when considering what to include in a portfolio of technological innovation that is worth pursuing.

8.3.4 Market formation (niche markets, feed in tariffs) (F5)

The creation of new (niche) market in Saudi Arabia is directly related to state support of policies to facilitate such a creation. Entrepreneurship and SMEs created in Saudi Arabia are emerging and will play a great role in forming (niche) markets in CM technologies.

Joint ventures (JV) seems to be a common method followed for creating markets in the Kingdom. Recent contracts were signed for solar energy development, such as Solar Frontier, a Japanese thin-film solar company, to install the largest PV-covered parking lot in the world of 40 acres to be completed in 2011 (Wesoff 2010).

A few companies [importing and] selling solar energy in Saudi Arabia are sprouting, such as Chemical Development Company (CDC), a company based in Al Khobar, Saudi Arabia, focuses on investing in solar energy, energy intensive chemical industries; Vision Electro Mechanical Company, a subsidiary of Construction Products Holding Company (CPC), is planning to build a first commercial solar power plant using CPV systems in Saudi Arabia (Business Wire 2010). There are other solar energy providers in Saudi Arabia (See POSHAL 2011) amongst which is Al-Afandi Solar Wafers and Cells Factory based in Jeddah, Saudi Arabia which was also mentioned in the previous chapter by one of the participants.

A \$380 million [£233 million] deal with South Korea for a clean energy collaboration has been sealed by Polysilicon Technology Company (PTC) which contracted South Korea's Hyundai Engineering and KCC Engineering and Construction Corporation to build a polysilicon plant on Saudi Arabia's Gulf Coast, enabling production of 3,350 metric tons of polysilicon, a material that turns sunlight into electricity (NERENBERG 2011, "*PTC a joint venture*

between Saudi Mutajadedah Energy Co (MEC) and South Korea's KCC Corp signed the engineering, procurement and construction contract with South Korea's Hyundai Engineering Co and KCC Engineering and Construction Corp.” The first phase of the project will be up and running by the first quarter of 2014, Ibrahim al-Humaidan, executive director of PTC told reporters. When all three phases of the project are complete -- at a cost of around \$1.2-\$1.5 billion -- in 2017, its polysilicon capacity will rise to 12,000 tonnes, Humaidan added (Shamseddine 2011).

Vision Electro Mechanical Company, a subsidiary of Construction Products Holding Company (CPC) – the industrial arm for Saudi Binladen Group⁵⁹ from the private sector, will build the first commercial solar power plant in Bahra, Saudi Arabia. SolFocus, based in Mountain View, California, will provide Concentrated PV systems.

These partnership companies that are sprouting in clean energy in Saudi Arabia are creating a market and it is hoped that this will activate supply and demand, which will inspire technological innovation in the clean energy sector by local individuals and companies as well as government initiatives.

8.3.5 Resources mobilisation (F6)

Resource Mobilisation include financial and human capital necessary as inputs for innovative activities such as investment by venture capitalists and government support; in terms of financial capital in Saudi Arabia, it is abundant and especially available if the political will is present. An open fund starting at \$10 billion is available for KAUST, whose prime focus is on technology innovation including renewable and clear energy technologies. Other recent efforts to promote sustainable energy receive generous endowments (e.g. KAPSARC, KACARE).

⁵⁹ Founded in 1931 (Modern Saudi Arabia was created in 1932), SBG is a multinational construction conglomerate and holding company for the assets owned by the bin Laden family, headquartered in Jeddah, Saudi Arabia.

Human capital, however, is scarce especially local talents and skills due to a developing education system, brain drain, instability in the region that makes the business environment unfavourable for foreign skilled labour to reside.

Saudi Arabia is a high-income country, according to SAMA's latest report (2010), Saudi Arabia enjoys a surplus economy with SR 1028.9 [£168.33] billion aggregate money supply and a total [actual] government revenues of SR 509.8 [£83.40] billion. While Saudi Arabia has strong financial resources, these are mainly derived from oil-resources, an equally important resource [mobilizations] is human resources.

In 2007, Saudi Arabia has pledged US \$300 million [£184 million] for research related to energy, environment and climate change, supporting clean technologies including CCS (IEA 2008, p.145). Such directions are important but also require skilled labour and effective project management to follow through and convert the grand dreams and vast resources into results.

8.3.6 Creation of legitimacy (F7)

This function is concerned with a political will that will overcome any counteract resistance to change and instead includes advocacy coalitions that will speed up the process in the system. Creation of legitimacy and support from advocacy coalitions are lobbying efforts to push compliance with legislation and institutions to overcome social inertia and resistance from other actors.

Given the centralised government structure in Saudi Arabia, the creation of legitimacy is lead by government institutions and how they drive other organizations. This could mean that if the government utilises this centralised structure of governance, a strategic decision – namely, an issuance of a royal decree by the King – to undertake investments in cleaner energy technologies could mean it would translate into government subsidies, government grants, creation of institutions and organizations, launching of projects and formulation of policies.

The main challenge of creating such legitimacy for CM technologies starts with an oil-based economy that already supports business and organizations that further ‘lock-in’ carbon into the economy. Government subsidies in the energy sector help provide a strong legitimacy for investments by the private sector in bringing in CM technologies and companies to uptake it, especially with a policy that supports its deployment.

For CM technologies, legitimacy includes parties calling for environmental sustainability, this includes environmental institutions like MEP, and also energy-related institutions like MOPMR Saudi Aramco, SABIC, SWCC. However, the power of legitimacy remains mainly from the government.

8.3.7 Co-evolution of Indicators

Having discussed the functions of SSCMSI, each function has been granted a score based on the performance of each function that was assessed using the findings from this dissertation. The radar chart below plots the results:

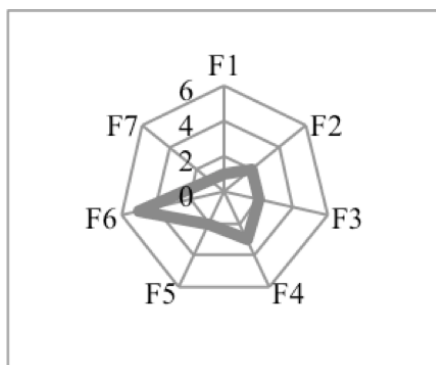


Figure 8-4 Scores for Functions of SSCMSI (Source: Author)

Key

F1	Entrepreneurial activities
F2	Knowledge creation/development
F3	Knowledge diffusion
F4	Guidance of the search
F5	Market formation
F6	Resource mobilization
F7	Creation of legitimacy

In order for the SSCMSI to be effective, these functions must work simultaneously and be exploited to reinforce each other. The co-evolution between the different functions ultimately determines the role of individual functions.

Competing technologies as well as carbon lock-in defines the state of the energy regime today. In technological competition, the market decides which technology wins out. However, in the energy sector in Saudi Arabia – which is characterised by a highly centralized approach to governance -- the ‘rules of the game’ change. Technological competition is not solely driven by costs, technological progress, and market conditions, but rather on energy policy, government subsidies, and government decisions.

Successful implementation of CM technologies in the Saudi energy sector is greatly dependent on the Saudi NSI developed around it as well as the technological innovation system of individual CM technologies. Moreover, it is all driven by a long-term vision that is suggested by landscape challenges. The materialisation of the SSCMSI naturally borrows from different IS approaches that were explained in chapter 4.

From a MLP, the Saudi cleaner energy innovation system could be seen as a sub-set to its NSI, but also as encompassing broader systems of networks. The technological system of innovation transcends national borders in that it represents a network of actors that include (1) the technology provider, typically companies that own the technology, (2) the R&D provider, such as research centres and [academic] institutions that are contracted by the host agency and (3) the technological [innovation] advancements in the public arena (SSI and TSI).

A number of researchers⁶⁰ argued that CCS may lead to [reinforced] fossil fuel lock-in, however, it is argued here that the portfolio of CM should in essence contribute in the transitioning towards sustainability, even if individual

⁶⁰ Unruh and Carrillo-Hermosilla, 2006; Markusson and Haszeldine, 2008; Vergragt, 2009.

technologies assist in prolonging the carbon lock-in. As discussed in 'contextualising sustainability', the meaning that is tied to the concept will change by changing phases, levels and scales. CCS is in fact a vital technology that will assist in utilising the vast Saudi oil reserves, which will in turn allow it to develop a sound economy with an infrastructure that supports technological innovations, particularly, cleaner energy; this will assist in the overall transition process towards sustainability.

Although it is discussed in the literature earlier that TIS as a framework disregards the geographical, regional and national -even- systems of innovation, it is important to establish an NSI that will encompass, enhance and flourish the development of TIS.

The SSCMSI will be defined by the network of actors interacting in a technological area under the existing institutional infrastructure, which will dictate its generation, diffusion and utilization of technology.

8.3.8 The state of the Saudi 'innovative capacity'

As a way of comparison, in this section, results from studies that are pertinent to the state of innovative capacity in Saudi Arabia is presented. Similar functions are needed to concentrate efforts towards spurring technological innovation, such as setting targets for increasing the number of publications in scientific journals, or increasing the percentage of spending on R&D, measured by gross domestic expenditure on research and development (GERD). This has been used as a yardstick by international institutions to assess the level of 'innovative capacity' in countries. For Saudi Arabia, the measurements recorded the following:

According to The Global Innovation Index (GII 2010), the table below shows Saudi Arabia's innovative capacity ranking in the region covering: Asia and Middle East, including New Zealand and Australia.

Table 8-3 Saudi Arabia's Innovative Capacity regional ranking according to the The Global Innovation Index (GII 2010)

<i>Type of ranking</i>	<i>Score</i>	<i>Rank</i>
Overall rankings	3.15	54
Innovation input	4.16	41
Innovation output	2.15	98
Regional ranking		17
Pillar: Institutions	4.17	74
- Political environment	3.79	71
- Regulatory environment	4.45	51
- Conditions for business provided by public institutions	4.26	106
Pillar: Human capacity	4.12	30
- Investment in education	4.72	11
- Quality of education institutions	3.97	53
- Innovation potential	3.68	45
Pillar: ICT and Uptake of Infrastructure	3.49	46
- ICT infrastructure	2.99	51
- General infrastructure	3.78	32
- Uptake and usage of infrastructure	3.71	49
Pillar: Market sophistication	4.36	29
- Investor and creditor conditions	4.74	42
- Access to private credit	3.99	29
Pillar: Business Sophistication	4.64	33
- Innovation environment in firms	4.52	15
- Innovation Ecosystem	3.98	44
- Openness to foreign and domestic competition	5.41	52
Pillar: Scientific Output	2.73	58
- Knowledge creation	2.61	42
- Knowledge application	4.52	16
- Exports and employment	1.06	109
Pillar: Creative Outputs & Well Being	1.57	123
- Creative output	1.03	93
- Benefits to social welfare	2.11	121

Fagerberg and Srholec (2009) studied a sample of 75 developing countries, amongst which is Saudi Arabia, figure 8-5 presents the state of Saudi Arabia as compared to top score. The study included the political system as one way that defined the innovativeness in an economy, Saudi Arabia showed very weak score in the 'political system' dimensions, relatively better openness, business regulation and financial system, lower performance on education system and technological capability.

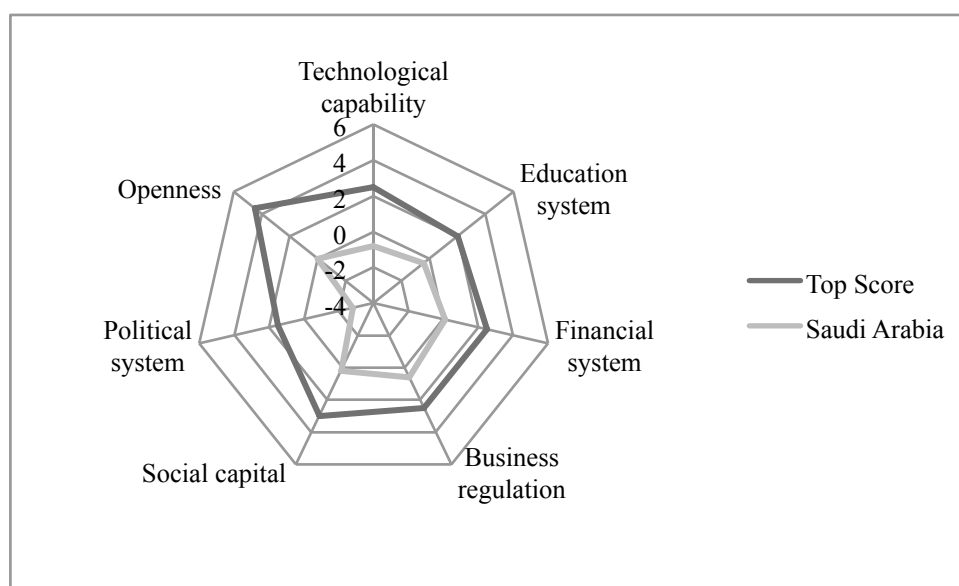


Figure 8-5 Saudi Arabia's Overall Score in Social Capacity, compiled by author (Data source: Fagerberg and Srholec 2009)

The table 8-4 shows the scores for Saudi Arabia.

Table 8-4 Scores for Saudi Arabia Social Capacity, compiled by Author (Data source: Fagerberg and Srholic 2009)

<i>Indicator</i>	<i>Top Score</i>	<i>Saudi Arabia score</i>
Technological capability	2.5	-0.8
Education system	2.0	-0.4
Financial system	2.5	0.1
Business regulation	2.5	0.6
Social capital	3.0	0.2
Political system	1.5	-2.8
Openness	4.5	0

Knowledge Economy Index with the Breakdown of Index of Four Pillars

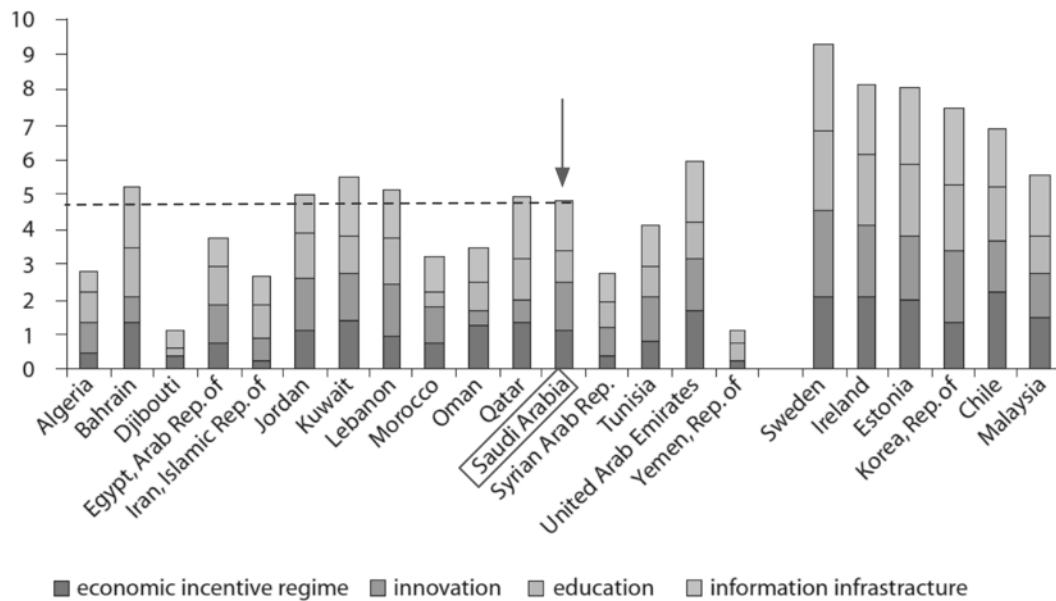


Figure 8-6 Knowledge Economy Index (Source: World Bank 2008, arrow added)

According to the World Bank (2008) study, Saudi Arabia's 'knowledge economy' index recorded 4.9, compared to 10 in Sweden and 1 in Yemen, for example. It is position in the middle between developing and developed countries.

The above reported studies compare to the findings from this chapter of the functions of its innovative capacity, especially in CM technologies. These offer insights into trends in the challenges that Saudi Arabia faces in building its innovative capacity.

8.4 Reflexive Governance for Saudi Arabia

Reflexive governance provides a useful framework for managing transitions towards sustainability. Related frameworks that preceded the framework also provides insights on how could Saudi Arabia manage its transition towards a cleaner energy economy whilst also promote technological innovation in CM technologies. This is done via incorporating sustainability principles in the processes of sustainable innovation policymaking (Chapter 4).

The reflexive governance approach suggests that policy-making must take a dynamic role by incorporating *visions* of sustainability as well as short-to medium-term *goals* for constructing transition paths. In order to spur technological innovation through innovation policy, a proposed framework for policymaking is presented. The aim is to break down the linear top-down decision-making that, arguably, often characterised policymaking in Saudi Arabia (Chapter 3).

Figure 8-2 provides a proposed vision with strategic goals and illustrative transition paths. The dashed lines represent policymaking. Reflexive governance suggest a cyclical structure for policymaking, this is accomplished by creating a dynamic interaction at all levels. At the micro level, technological innovations are created through rigorous R&D and experimentation, these learning-by-doing activities and processes inform policymaking, which in turn shape policies. Visions are revisited to redefine strategic goals to fit the status quo.

8.4.1 Strong political will via royal decrees

Traditionally, policies in Saudi Arabia have been generated as a top-down approach. Typically, the King is regarded as the top authority that influences policy through the administrative setting (Chapter 3), or through royal decrees

that are the fastest way to implement 'quick-fix' policies. For example, the creation of Saudi Aramco, SABIC, KACST, KAUST, KAEC, KAPSARC, KACARE are as a result of decisions by the King. Hence, discussion about market forces become negligible and non-market mechanisms are very present, such as public policy and its ability to meet objectives, this is regarded as much more important in driving change. More importantly, the question is how can royal decrees play a role in spurring innovation in the energy sector.

The nature of the governance, which defines the current institutional/political structure in Saudi Arabia, is largely maintained by a top-down approach, this however is problematic when it comes to the innovative capacity building in the country. The science and technology arena in particular requires both top-down, government regulations, taxation, funding, subsidies, as well as bottom-up, market forces, technological competition, R&D efforts; these are examples of how dynamic the relationship must be.

However, this challenge is also an opportunity that could be seized. The constituents of transition management in the Kingdom is very much centred around the role of the government, and its initiative that will allow its current policies to generate long-term vision, achieve vertical and horizontal coordination of policies, and perform innovation-oriented activities and processes that will allow the transition of its NSI, such as portfolio management, process management and exploiting strategic experiments of new energy technologies.

8.4.2 From oil policy to cleaner energy innovation policy

The case for Saudi Arabia changes the typical meaning of innovation policy, there are two views in the literature, developed nations use innovation policy that is focused on the bases of an industrial economy or a service-based economy, or on the other hand, developing nations that use economic policy to strengthen the economy and basic infrastructure. Saudi Arabia is neither of the two; its resource-based economy achieved economic development that

supports basic infrastructure but still has characteristics of weak institutions. An evolution from oil policy must be made towards innovation policy.

Oil policy and oil-related decisions in Saudi Arabia are highly determined by geopolitics, national strategic interests and oil prices. Driven mainly by economic factors and political considerations, oil policy-makers include a dozen of individuals that represent government institutions, supreme council for petroleum and mineral affairs, and the ministry of petroleum and mineral resources. Saudi Arabia also believes that technological innovation (from various TSIs) greatly influence policymaking and for that it must prepare for prudent policymaking that takes into account the importance of making energy policy inclusive of CM technologies.

As has been summarized in Chapter 5, innovation policy is R&D policy, technology policy, infrastructure policy and education policy - interlinked. Innovation policy in Saudi Arabia could be seen as the overarching policy which interlinks the main foundations in its economy. Saudi NSI as well as the Saudi approach to policy-making dictates the fate of innovation policy. Ultimately, this should evolve from traditional centrally-planned policymaking towards system thinking, system innovation policy regime, institutional basis, sustainable innovation and policy learning. This 'reflexive' mode of governance suggests continuous learning even at the policy level.

Policy learning should be integrated as part of the sustainable innovation policy process, especially given this is at its infancy stage in Saudi Arabia. It becomes necessary that the institutes that are central in sustainable innovation policy, such as KACST, SAGIA and MEP, (i) monitor and evaluate the implementation of policies, (ii) review its impact on sustainable innovation system, and (iii) learn and enrich the policy process in return.

After considering the actors/agents within SSCMSI, Saudi Arabia must gear its cleaner energy innovation policy towards sustainability vision and strategic goals defined in Figure 8-2 that will enable it to:

- Formulate technology-specific policies

Policies for each energy technology option (transition path) must be formulated to allow its adoption and development. Such policies could include research grants that will invite local research centres and educational institution to participate in R&D, as well as pilot projects which allows trial-and-error and experimentation.

- Long-term technology development

Developing 'technology roadmaps' for individual technological options, with performance criteria and objectives to be used as benchmarks for the transition paths. Such roadmaps must be communicated with policymakers and not remain isolated in research centres of companies. Actors that are involved in technology development will include companies outside the national borders; however, cooperation for technology transfer and knowledge learning must be activated so as to enrich local actors.

- Long-term market mechanisms

Market mechanisms are defined by demand-pull and supply-push. Currently, outsourcing and buying technologies from abroad fill gaps created by demand-pull in the energy and electricity sectors, a supply-push can be created by empowering local actors, providing research grants, and funding entrepreneurship to maximize their participation in the innovation process.

8.4.3 LCA as a sustainability tool:

In chapter 7, LCA studies on CCS and Solar PV have provided a quantitative reasoning to pursuing such cleaner energy technologies. For environmental sustainability, in particular, these two technologies offer tremendous opportunities to reduce CO₂ emissions. But even more importantly, CCS offers an opportunity to maintain the use of oil, continue to support a heavily dependent economy on oil, and also facilitate a transition towards sustainability by immediately reducing CO₂ emissions by 70-80%. But because CCS uses more energy, and therefore produces more CO₂ that

needs to be sequestered, it is not seen as a completely environmentally sustainable option.

Also, currently Saudi Arabia uses a considerable amount of water for EOR and currently faces serious water shortages, as discussed in chapter 3. Using liquefied CO₂ for EOR would contribute in saving water and reduce shortages in water. Thus, CCS-EOR is a more sustainable option, at least for the short- to medium-term in this regard.

Conducting LCA studies should provide the feedback for governance on issues relating to environmental sustainability. LCA results can inform policy by providing predictive transition pathways towards environmental sustainability. In the Saudi case, Solar PV and CCS have both been used to project future CO₂ levels in Saudi Arabia.

From chapter 6, different scenarios (transition paths) have been generated using the two technologies of CCS and Solar PV, using different energy mix and growth cases. The proposed scenario (Table 6-16) was using 90% CCS-fitted fossil fuels and 10% solar on new power generations, reducing CO₂ emissions from 292 to 148, saving 144 MtCO₂. Applying the same methodology on different energy technology options will generate a similar result and will therefore shape policymaking.

From figure 8-2 a cyclical approach is suggested that is placed at the heart of reflexive governance, at the level of technologies, procedures for ‘managing’ an effective transition path, which is embedded in SSCMSI, experimentation and R&D activities will allow the system to analyze the elements (agents) of the innovation system, this will help identify priorities and thus the allocation of resources; it will also allow the monitoring of each of its functions to determine flaws in the system, and therefore stimulate flawed functions and monitor again. This continuous assessment of transition paths should work simultaneously with policymaking to achieve the defined vision and strategic goals.

Using the current strengths and competitive advantages of the economy and utilising it to reach a new vision. For example, the state-owned SABIC is a world's largest petrochemical company, focuses on producing chemicals, polymers and fertilizers, could carry extensive LCA studies on technologies to identify and create a portfolio of carbon-based technologies that are deemed useful for the transition process. It has a massive opportunity to lead in carbon-based industry. In this case, the resources are readily available; an informed decision can immediately activate this vision via reflexive policy recommendations.

8.4.4 International involvement in Saudi Arabia

International organisations and international corporations have played a significant role in the shaping of policies since the creation of modern Saudi Arabia. The inherent advantages that such organizations bring about in a country is well-established in the literature, it includes the expertise and know-how that international companies bring with them to the country via its various branches.

The role of international institutions in providing assistance for the process of developing the innovative capacity in a country is especially important in developing countries. This was evident in Saudi Arabia technical change (chapter 3). Major events that was assisted by international actors: the creation of Saudi Aramco, the establishment of planning (MEP), the establishment of NIE project could be regarded as a major step in gearing efforts towards creating an innovation-based approach to economic development, as well as the creation of new (economic/knowledge) cities.

The continuation of international involvement in Saudi Arabia is important for supporting innovative activities and advancing the SSCMSI. However, more structured activities and collaboration projects need to be pursued.

8.5 Conclusion

The dissertation started with a question concerning the fate of the energy sector in Saudi Arabia, namely, how transition pathways towards a cleaner

energy economy can be constructed. The process can be summarised in the following:

1. System materialization

The first step was to identify the NSI in Saudi Arabia, this is the result of an account of economic development over the decades to identify the main forces as well as actors (agents) that shaped the economy. The 'materialisation' of NSI has also been informed by 30 participants in the research, it helped organise the structure and identify relationships and networks between and within agents.

2. System activation

Similar to an established grid ready to be plugged-in, the aim is to activate the system after it has been materialised. 'Materializing' a system of innovation in a country helps to understand the structure underlying innovations. System activation involves the connection between actors and within them to stimulate the process of system innovation. The (qualitative) research helped identify gaps in the Saudi NSI, which challenges the activation of the system.

3. System management

The maintenance of the performance of NSI is by itself a sustainability criterion. This 'system innovation' is innovation in the managing of the system and how it could encompass change and transition towards the vision of sustainability.

The research proposed a transition management framework, the SSCMSI, building on NSI and using the (quantitative) research that helped construct transition paths towards sustainability. A review of 40 LCA studies on CCS and Solar PV has helped construct different transition paths towards cleaner energy. Managing transitions involved a reflexive mode of governance to maintain a dynamic dimension for policymaking. Thus, findings from experiences could shape policymaking, as well as using a long-term vision, together they inform strategic goals that are sought-after.

The general framework is sustainability, which provides an ultimate 'utopia' that inspires attainable objectives. The Saudi definition of sustainability includes the utilisation of its natural resource, oil and gas, and its marketability in the world. The reader might understand that the question of transition towards cleaner energy is largely Western-driven, since their dependence on Middle Eastern oil and especially Saudi oil provoke energy security and national security concerns. However, this dissertation, although started with such a discourse, took a different route throughout its making.

It is because the subject of oil is highly related to, if not defined by, politics. Geopolitics determine the fate of the international oil market and even though international institutions seem to create rules for oil movement, such rules have in fact further institutionalised the oil market to suit the international community, mainly Western, interests.

The issue of sustainability is therefore highly contextual and politicized when the oil market is considered. Sustainability for Saudi Arabia is maintaining the demands on oil, this today will not be attainable unless Saudi Arabia pursues a transition path towards diversification and therefore cleaner energy. International environmental regulations will inevitably provide a stricter regulation in electricity generation, transportation and perhaps even business conduct.

Pursuing sustainability in the energy sector must be parallel to the country's quest for sustainability, including its environmental consciousness, greater economy development, and social development. Therefore, the development of a country's energy sector cannot be pursued in isolation, 'spurring of innovation' is built on an activated NSI.

Innovation, therefore, is to be spurred not only at the micro level (in strategic niches) but also in the meso, country-level to innovate in policy-making and innovate in managing such transitions of the whole economy. It is because innovation occurs as a result of a complex process characterized by systemic

interaction, relationships, networks and feedback mechanisms, understanding a country's NSI is the first step for technological innovation.

Escaping 'challenges' impeding Saudi Arabia's transitioning towards sustainability means activating Saudi's NSI and accelerating transition paths. The question becomes how could Saudi Arabia pursue sustainability, rather than how could Saudi Arabia apply CCS or Solar energy to its oil & gas and energy sectors.

In conclusion, SSCMSI role has been defined to encompass: accelerating innovation in the energy sector, encouraging energy efficiency, accelerating the use of renewable energy, improving market conditions, supporting technology transfer from advanced economies, utilising international cooperation and mobilizing private sector investment in energy.

9 Conclusion

This is the final chapter of the dissertation. It states a brief summary of what has been done, it evaluates the extent to which the research questions and objectives have been answered and met. It also sets out the main limitations and provide some key points for further work.

Chapter Content:

9.1 Introduction

9.2 Evaluation

9.3 Limitation

9.4 Further work

9.1 Introduction

This chapter recaps on the ideas developed throughout the dissertation. It starts with a brief summary on what has been done so far. Next, it evaluates the extent to which the research questions have been answered, and the research objectives have been met. It then sets out the limitations in this dissertation, and finally ends with key points for further work.

As presented, the dissertation started with a central research question which entails: how could Saudi Arabia, given its oil-based economy and vast oil reserves, respond to the challenges of climate change with the world's possible transitioning towards environmental sustainability, and away from fossil fuels. In order to answer the question, the dissertation has covered the following:

9.1.1 Background issues motivating the topic

Chapter 2 on climate change provided a summary of the current knowledge and scientific consensus of the world authorities, presenting key indicators, causes and projections. The chapter has also summarized the possible direct and indirect effects on Saudi Arabia. An antidote discussion on natural climate variability was then provided to revoke the arguments that support the consensus. The chapter explained that climate change refers to a global warming in the climate that is caused by rising levels of greenhouse gases, and carbon dioxide in particular, to the naturally-occurring greenhouse effect. It is believed that climate change is a result of anthropogenic (human-induced) effects with a direct casual effect since the industrial revolution. The conclusion showed that Saudi Arabia remains to be highly vulnerable to climate change, with 76% of its land non-arable and 38% being desert. Costs for growing crops have significantly grown in the past that wheat is no longer producible in the country and instead is being imported, such changes in crops cultivation are expected to continue as climate change effects spread and further precipitate the problem. In addition, the global effect of climate change is counter-productive and traps the world in a vicious cycle, which will

eventually lead to adverse climate effects in Saudi Arabia affecting not only its environment but also eventually human's health and life.

Chapter 3 on Saudi Arabia introduced the country case study, it started by providing a brief overview on the country's profile and a summary on the Saudi economic development since its inception with a focus on the energy sector. It was discussed that Saudi Arabia's oil discovery has placed the oil sector at the heart of its economic development. It has fuelled the development of its energy sector and placed the country as an oil economy, a regional financial power horse and a leader of energy. Saudi Arabia has enjoyed a leadership role for decades and continues to do so in the GCC, Middle East and the Arab/Muslim world. Its role in the world economy is only expected to grow in significance, in the area of oil exports. Efforts combating climate change are at their initial stages and policies to promote environmental sustainability and technological innovation are yet to be established. Challenges were summarized at the end of the chapter and included the following: diversification of its oil-based economic base, energy supply and demand securities, rising local demands due to urbanization and booming population, and the weak infrastructure to lead a science, technology and innovation and hence knowledge-based competitive national economy.

9.1.2 Frameworks to guide the case study

Chapter 4 has provided an articulation of the theoretical frameworks for transition pathways in a national system of innovation (NSI). The chapter focuses on the original frameworks of NSI as introduced but also borrowed TSI functions that appeared after in the literature to fit the case study of Saudi Arabia. Moreover, sustainability, transition management, and reflexive governance have been summarized to be applied in the dissertation. The chapter also covered a section on methodology.

9.1.3 Carbon management technologies

Chapter 5 provided a technology chapter presenting a portfolio of carbon management technologies selected for Saudi Arabia. The chapter provides an

understanding of the technology, its status and deployment around the world and the potential it has in contributing to Saudi Arabia's carbon management (CM) system of innovation. These are 'technology innovations' that are born at the *micro* level and correspond to a multidisciplinary of sectors that include but are not limited to the energy sector: carbon capture and storage (CCS), solar energy, and carbon industrial uses.

9.1.4 Findings, analysis and discussion

Chapters 6, 7 and 8 then presented and analyzed the overall findings of the dissertation: two studies, a quantitative inquiry reporting life cycle assessment (LCA) results, which help construct environmental sustainability transition pathways for the case study of the Saudi energy sector (chapter 6), and a qualitative inquiry reporting interview results, which feed into materializing the Saudi NSI (chapter 7). Together, these two sets of findings were combined to produce a higher level of analysis and discussion that intertwine the qualitative findings with the quantitative findings in the light of the literature to present a possible *sustainable CM approach for the Saudi NSI* (chapter 8).

9.2 Evaluation

This section evaluates how research questions have been addressed. The dissertation attempted to answer the central research question: How could Saudi Arabia, given its oil-based economy and vast oil reserves, respond to the challenges of climate change and the world's transitioning towards environmental sustainability, and away from fossil fuels?

The answer to this rather general question is not straight-forward and complex in terms of encompassing sequential steps to answering, mainly following the five sub-questions:

1. Why is a transition to sustainability in Saudi Arabia important?

The need for a transition towards sustainability in Saudi Arabia has been developed in the first three chapters (1-3). The problem statement presented the challenges for Saudi Arabia which were four-folds: climate change impacting the world and Saudi Arabia, interest in alternative energy making a

possible world shift away from fossil fuel, legal and environmental obligations towards the international community and more intensified challenges facing the Saudi oil industry, such as decreasing the dependence on Saudi oil, oil price fluctuations and rising energy consumption in Saudi Arabia. Therefore, a transition towards sustainability in Saudi Arabia is indeed important.

2. What is Saudi Arabia's NSI?

In order to understand and materialise what is Saudi Arabia's NSI, *first*, it was necessary to provide an overview on Saudi Arabia, its economy and energy sector (chapter 3). Providing an overview on the country profile, presenting an understanding of the energy sector, and outlining the stages of economic development, and also listing key milestone in sustainable energy in Saudi Arabia. *Second*, by reviewing the relevant literature on the theoretical and analytical frameworks around NSI (chapter 4), introducing the system of innovation approach, including NSI.

3. What is the portfolio of carbon management technologies that could assist Saudi Arabia in such a transition?

To create a portfolio of carbon management technologies, the background chapter on climate change (chapter 2) as well as the discussion on sustainability, transition management and reflexive governance as a conceptual and theoretical framework (chapter 4), and the transition provided a good starting point to identify the required technologies for a transition towards sustainability.

4. What might be the socio-technical transition paths that Saudi Arabia could pursue for sustainability?

Taking the transition paths into a deeper level, by following the literature from conceptual and theoretical frameworks on multilevel perspective and socio-technical transition paths (chapter 4) and in light of the previous background chapters (1-3). Transition pathways were constructed based on the studies conducted, the scenarios on LCA on CCS and Solar PV (chapter 6) and the

materializing of Saudi NSI (chapter 7). This question was addressed more specifically by combining both findings and presenting a new level of understanding and analysis (chapter 8).

5. What are the energy and innovation policies that Saudi Arabia could adopt to achieve sustainability?

The final outcome of energy and innovation policies was built on all the above (chapter 1-8), specifically, the discussion on transition management and reflexive governance (chapter 4) has helped guide and write the recommendations that were set out based on the transition pathways constructed for Saudi Arabia. This question was addressed as a reflection on the current status of Saudi Arabia and where it is hoped it will be position in the medium-long term.

9.3 Limitation

The main limitation of this dissertation lies in the complexity of the research design. It is because the subjects involved are based in different disciplines, it was a challenge to follow the right research methods, and the type of research to be studied, combining two different types of studies, generating findings and analysing and discussing. The chosen methodology, although enabled addressing the questions in an effective manner, however, it also limited the research in a way, as it was difficult to combine two different kinds of findings and make sense of it in the overall findings.

Another challenge faced was with the qualitative study more specifically, the research questions and the limited information / participants that are experts about the topic. It is because the materialisation of the national system of innovation is a complex matter as well as an original pursuit; it was difficult not to build on previous works on the literature on the case study of Saudi Arabia. It is true that a comprehensive literature review was done on other countries' NSI; however, the uniqueness of the country case of Saudi Arabia makes it difficult to accurately materialise its NSI.

Moreover, the quantitative study design was also limiting, as it was necessary to choose one or two energy technologies to have a feasible study to create scenarios. Therefore, it could be another technologies than CCS and Solar PV; however, for the sake of this dissertation it was necessary to choose only two. Also, the LCA studies have many assumptions that limit the applicability to the case study. Ideally, it would have been more precise to generate one's own data using an LCA on each technology.

In addition, the findings from the dissertation gave an illustrative vision of Saudi Arabia and could be seen as too theoretical. However, the policy recommendations derived from these could balance it out, as it is more practical.

9.4 Contributions to knowledge

Going back to the expected contributions stated at the start of this dissertation (chapter 1), the dissertation has indeed met and exceeded its expected contributions:

9.4.1 Methodological contributions

Methodological contributions could be derived from the use of mixed methods in the unique research design of the dissertation is original in the sense that the quantitative LCA modelling studies were combined with the qualitative study of Saudi NSI and then incorporated into the overall qualitative case study research. The frameworks used are based on the social sciences domain (sustainability, NSI and transition theories) whereas the LCA modelling tool is based on the science and engineering domain.

9.4.2 Theoretical contributions

The theoretical contributions could be seen in incorporating encompassing conceptual frameworks, and the combining of different theoretical frameworks to the subject matter. (1) Incorporating sustainability as an overarching concept that guides the direction of NSI and transition pathways. (2) Combining LCA as a *sustainability* tool to build scenarios based on LCA studies data. (3) Using transition management and theories to construct

transition pathways and propose an approach for the case study. (4) Applying the reflexive governance framework to develop energy and innovation policy recommendation for the case study.

9.4.3 Empirical contributions

The empirical contributions are the easiest to identify as they make up the main contributions in this dissertation. (1) The materialisation of the national system of innovation in Saudi Arabia using the case study research and the interviews of thirty participants from the across the economy in institutions that make up the agents of Saudi NSI. (2) The compiling of carbon management technologies portfolio based on the case study of Saudi Arabia and the sustainability transition, more specifically, those technologies that are pertinent in the short-medium run as per the sustainability objectives of the corresponding timescale. (3) LCA modelling of energy consumption and carbon dioxide emissions for two energy technologies from the CM technologies portfolio, CCS and Solar PV for years 2010-2025 for the Saudi energy sector. (4) the combining of findings from two studies to build the sustainability transition pathways for Saudi Arabia in order to create the SSCMSI. (5) Drawing policy recommendations using the reflexive governance framework for the country case study.

9.5 Further work

Some key points to consider in this dissertation for further work, include (1) the expansion of the current scope of research to include country cases with similar challenges, for instance, oil-based developing economies. (2) The development of a portfolio of carbon management technologies that are pertinent to the long-term view, such as nuclear energy, more solar energy applications (e.g. CSP), energy storage technology, sustainable desalination technologies, etc. (3) developing a fully-fledged LCA model for each technology, especially for technologies that have not been developed in an LCA study. This will be original as it will enable producing primary data on carbon dioxide emissions, energy use, etc. It will also enable the selection of environmental criteria under study.

The research opens many doors for future research, after all, the sustainability criterion in the research suggest continuous pursuit in many areas that could be explored in the energy technology and innovation arena.

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8 Appendices

8.2 Appendix A6.1

Low Growth Case

Low Growth Case					
	1	2	3	4	5
	Growth Rate	Energy / GJ	Carbon Emissions / t CO ₂	Mean Load / MW	Peak Load / MW
2010	3.54%	741,944,466	171,561,149	24,001	35,423
2011	3.54%	784,664,157	177,857,298	24,882	36,723
2012	3.54%	813,460,665	184,384,509	25,795	38,071
2013	3.54%	843,313,980	191,151,264	26,741	39,468
2014	3.01%	868,697,730	196,904,917	27,546	40,656
2015	3.01%	894,845,532	202,831,755	28,375	41,880
2016	3.01%	921,780,383	208,936,991	29,229	43,140
2017	3.01%	949,525,972	215,225,994	30,109	44,439
2018	3.01%	978,106,704	221,704,297	31,016	45,776
2019	2.61%	1,003,635,289	227,490,779	31,825	46,971
2020	2.61%	1,029,830,170	233,428,288	32,656	48,197
2021	2.61%	1,056,708,737	239,520,767	33,508	49,455
2022	2.61%	1,084,288,835	245,772,259	34,383	50,746
2023	2.61%	1,112,588,774	252,186,914	35,280	52,070
2024	2.61%	1,141,627,341	258,768,993	36,201	53,429
2025	2.61%	1,171,423,815	265,522,864	37,146	54,824
2026	2.12%	1,196,257,999	271,151,948	37,933	55,986
2027	2.12%	1,221,618,669	276,900,370	38,737	57,173
2028	2.12%	1,247,516,985	282,770,658	39,559	58,385
2029	2.12%	1,273,964,345	288,765,395	40,397	59,623
2030	2.12%	1,300,972,389	294,887,222	41,254	60,887
2031	1.66%	1,322,568,531	299,782,350	41,938	61,898
2032	1.66%	1,344,523,168	304,758,737	42,635	62,925
2033	1.66%	1,366,842,253	309,817,732	43,342	63,970
2034	1.66%	1,389,531,834	314,960,706	44,062	65,032

2035	1.66%	1,412,598,063	320,189,054	44,793	66,111
2036	1.19%	1,429,407,980	323,999,304	45,326	66,898
2037	1.19%	1,446,417,935	327,854,895	45,866	67,694
2038	1.19%	1,463,630,308	331,756,369	46,411	68,499
2039	1.19%	1,481,047,509	335,704,269	46,964	69,315
2040	1.19%	1,498,671,974	339,699,150	47,523	70,139
2041	0.73%	1,509,612,280	342,178,954	47,870	70,651
2042	0.73%	1,520,632,449	344,676,860	48,219	71,167
2043	0.73%	1,531,733,066	347,193,001	48,571	71,687
2044	0.73%	1,542,914,717	349,727,510	48,926	72,210
2045	0.73%	1,554,177,995	352,280,521	49,283	72,737
2046	0.26%	1,558,218,858	353,196,450	49,411	72,926
2047	0.26%	1,562,270,227	354,114,761	49,539	73,116
2048	0.26%	1,566,332,129	355,035,460	49,668	73,306
2049	0.26%	1,570,404,593	355,958,552	49,797	73,497
2050	0.26%	1,574,487,645	356,884,044	49,927	73,688

8.3 Appendix A6.2

High Growth Case

High Growth Case					
	1	2	3	4	5
	Growth Rate	Energy / GJ	Carbon Emissions / t CO ₂	Mean Load / MW	Peak Load / MW
2010	6.33%	794,679,605	183,377,509	25,199	37,192
2011	6.33%	848,382,198	194,985,306	26,902	39,705
2012	6.33%	905,713,887	207,327,875	28,720	42,388
2013	6.33%	966,919,918	220,451,730	30,661	45,253
2014	7.91%	1,043,403,284	237,889,462	33,086	48,833
2015	7.91%	1,125,936,483	256,706,518	35,703	52,695
2016	7.91%	1,214,998,059	277,012,004	38,527	56,863
2017	7.91%	1,311,104,406	298,923,653	41,575	61,361
2018	7.91%	1,414,812,764	322,568,514	44,863	66,215
2019	10.03%	1,556,718,484	354,922,136	49,363	72,856
2020	10.03%	1,712,857,348	390,520,826	54,314	80,164
2021	10.03%	1,884,656,940	429,690,065	59,762	88,204
2022	10.03%	2,073,688,031	472,787,979	65,756	97,051
2023	10.03%	2,281,678,941	520,208,613	72,352	106,785
2024	10.03%	2,510,531,339	572,385,537	79,608	117,496
2025	10.03%	2,762,337,632	629,795,806	87,593	129,281
2026	11.79%	3,088,017,239	699,950,923	97,920	144,523
2027	11.79%	3,452,094,471	782,475,137	109,465	161,562
2028	11.79%	3,859,096,409	874,728,955	122,371	180,610
2029	11.79%	4,314,083,876	977,859,499	136,799	201,904
2030	11.79%	4,822,714,365	1,093,149,134	152,927	225,709
2031	13.64%	5,480,532,605	1,242,254,676	173,787	256,495
2032	13.64%	6,228,077,252	1,411,698,214	197,491	291,481
2033	13.64%	7,077,586,989	1,604,253,850	224,429	331,239
2034	13.64%	8,042,969,854	1,823,074,076	255,041	376,421

2035	13.64%	9,140,030,942	2,071,741,380	289,829	427,764
2036	15.49%	10,555,821,735	2,392,654,119	334,723	494,025
2037	15.49%	12,190,918,522	2,763,276,242	386,572	570,549
2038	15.49%	14,079,291,801	3,191,307,732	446,452	658,928
2039	15.49%	16,260,174,101	3,685,641,300	515,607	760,995
2040	15.49%	18,778,875,069	4,256,547,137	595,475	878,874
2041	17.34%	22,035,132,006	4,994,632,411	698,730	1,031,270
2042	17.34%	25,856,023,896	5,860,701,671	819,890	1,210,093
2043	17.34%	30,339,458,440	6,876,947,341	962,058	1,419,923
2044	17.34%	35,600,320,534	8,069,410,010	1,128,879	1,666,137
2045	17.34%	41,773,416,114	9,468,645,706	1,324,627	1,955,045
2046	19.19%	49,789,734,666	11,285,678,816	1,578,823	2,330,219
2047	19.19%	59,344,384,749	13,451,400,581	1,881,799	2,777,388
2048	19.19%	70,732,572,182	16,032,724,353	2,242,916	3,310,368
2049	19.19%	84,306,152,784	19,109,404,156	2,673,332	3,945,628
2050	19.19%	100,484,503,503	22,776,498,814	3,186,344	4,702,794

8.4 Appendix A7.1

Sample questions of research interviews:

Interview Questions

Part I - SAUDI ECONOMY

1. What are the main agents in Saudi Arabia that contribute to economic development? in the following:
 1. Government agencies
 2. Research Institutions
 3. Industrial Pillars
 4. Academic institutions
2. What is the nature of the relationship between Industry-Academia-Government.
3. How do you explain the communication within agents and outside agents?
4. How do you describe Saudi's knowledge and learning process that leads to economic development? In terms of knowledge generation, diffusion and use. (i.e. towards a knowledge economy)
Or in your words: *the absorptive capacity* and *technological learning*. Any 'reverse engineering'?
5. What are the trends for the process of competition and selection within markets (demand-side for technology)? Any sources that you could recommend?
6. Can you explain what is the rate of technological change in Saudi's economy? Examples? Where could I get this type of data? Which sectors within the economy are active in this regard?
7. The role of technological innovation in economic development over the past years?
8. Could you explain the nature of communications within the Saudi ministries that are directly related to the economy?
9. Are there policies to promote innovation (technological and others) within the economy?
10. What are the already implemented policies that guided, assisted or promoted economic development?

Part II – Saudi Energy Sector

1. What are the lines of communication from/to the oil industry within and outside Saudi Arabia? Knowledge flows, networks
2. How do you explain the technological developments within Saudi's energy sector? (Data on the technological developments and who contributed to those? What are the causes or impacts)

Part III – Saudi Alternative Cleaner Energy Options

1. What does 'sustainable development' and 'climate change' mean to you?
2. Do you think it is necessary for Saudi Arabia to pursue transition paths to sustainability?
3. If yes, how? And by who? (which organizations)
4. Are there any policies developed and implemented until now in SA response to climate change? Is it necessary?
5. Do you believe a transition to a cleaner energy economy for Saudi could be achieved? In what way? Timescale? Costs? Agents?
6. Are there policies that promote developing cleaner energy technologies?
7. What is the status of solar technologies?
8. What are the incentives of going renewable?
9. Are there efforts in exploiting renewable energy sources for the generation of electricity or power?

Part IV – Saudi Carbon Management Technologies

1. What are the developments in carbon management technologies in Saudi's energy sector? Is it necessary?
 - a. What are the implications, if any? On the oil markets?
 - b. What are the plans in that regards?
2. Are there any research activities on Carbon Capture?
3. Is the current transport infrastructure of shipping and/or piping is suitable for Carbon Transport?
 - a. Carbon Sequestration
 - i. Geological
 - ii. Oceanic
 - b. Mineral Carbonation
 - c. Carbon-based applications

Part V – Saudi Energy Policy, Politics and Legal Issues

1. What is the position of Saudi Arabia regarding the legal framework under climate change policies?
2. What is the incentive to go cleaner? If any.
3. Who will be responsible for policy of CM? Is there any undergoing activity?
4. Which companies who work with CDM are interested in projects in CO2?
5. Can you refer me to someone in the team that is experimenting CO2 capture?

10.1 Appendix A7.2

Explaining Agents Ranking in NSI

If you refer to the sample of interview questions in Appendix A7.1, the first part on Saudi Economy starts with the following question:

1. What are the main agents in Saudi Arabia that contribute to economic development? in the following:
 1. Government agencies
 2. Research Institutions
 3. Industrial Pillars
 3. Academic institutions

Each participant was asked to answer the question by stating the agents in the order of influence to economic development in Saudi Arabia. After all participants have completed their lists, all thirty lists were combined under each group: Government agencies, Research Institutions, Industrial Pillars, and Academic institutions.

The ranking of agents under each group followed the sequence:

- All agents were included in the final lists in each group
- Each agent was given a score of one point at each order in each group
 - o The agent that received most points is placed at the top in that group to indicate power of influence.
- For example: under Government agencies, in the first place, if nine people ranked SAGIA to be on top of the list, then SAGIA gets the score of nine in the first place.

The same sequence was followed to identify the ranking of agents in each group. At the end, the thirty participants' average view on the agents and their ranking of power of influence to economic development in Saudi Arabia was reflected in chapter seven's results, findings and discussion.